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EFFECTS OF SIMULATED SURFACE EFFECT SHIP MOTIONS ON CREW HABITABILITY—PHASE II

VOLUME 2

FACILITY, TEST CONDITIONS, AND SCHEDULES

Prepared by
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From July through September 1975, a series of ship motion simulation experiments was conducted using the ONR Motion Generator at Human Factors Research, Inc., Goleta, CA. These experiments (designated Phase II) are the latest in a continuing program of the Surface Effect Ship Project Office to establish the effects of SES motions on the health and performance of crew members. In earlier tests, the motion generating equipment was unable to replicate the higher acceleration and velocity portions of the commanded motion waveforms, which were derived from computer simulations of the SES encountering open-ocean seas at high speed. During April - June 1975, extensive modifications were made to the ONR Motion Generator in order to improve its capability to provide SES-like motions. These modifications and the resulting system performance during the Phase II tests are described.

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18. SUPPLEMENTARY NOTES (continued)

motion on crew health and performance. Other organizations preparing the companion volumes are Naval Sea Systems Command (PMS-304), Human Factors Research, Inc., and Naval Aerospace Medical Research Laboratory Detachment.

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PREFACE

This project was Phase II of a large-scale investigation of high-speed-ship habitability (crew motion effects) by the U.S. Navy Surface Effect Ship Project (SESP, Code PMS-304 located at the David Taylor Naval Ship Research and Development Center, Carderock, Maryland). Activities of all participants were closely directed, coordinated, and participated in by two key SESP personnel:

LCDR J. Michael Vickery, Royal Navy (PMS-304-40A)

Mr. Warren Malone (PMS-304-42)

The other Naval agencies participating (along with their key roles and personnel) were as follows:

Naval Aerospace Medical Research Laboratory, Detachment at Michoud, Louisiana (NAMRLD)

Crew volunteers and medical tests, medical monitoring, head motion measurements.

Capt. Channing Ewing, MC, USN; CDR Paul Majewski, MC, USN; Dr. Dan Thomas, M.D.; Dr. John C. Guignard, M.D.

For privacy reasons the names of the 19 Naval enlisted personnel who volunteered as test crewmen cannot be listed, but their perseverance despite sometimes unpleasant environments and tasks deserves commendation.

Naval Ship Research and Development Center, Ship Dynamic Simulation Branch at Carderock, Maryland (NSRDC)

Recording system, motion tapes, and analyses

William Smith, Robert Stanko, David Milne

The test facility was developed and operated under Office of Naval Research (Code 444) sponsorship by Human Factors Research, Inc. (HFR) at Goleta, California. HFR also conducted several experiments and coordinated all logistics. The principal personnel supporting this Phase II work were: Dr. James F. O'Hanlon, Mr. M. L. Seltzer, Dr. A. Harabedian, Mr. Glenn Sanderson, and Mr. Greg Bailey. At Systems Technology, Inc., several persons besides the authors were heavily involved in the work reported herein: Jeffrey R. Hogge, James Nagy, and Daniel Swanburg.

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INTRODUCTION

A. CONTENTS

This second volume on the Phase II Surface Effect Ship (SES) motion simulation describes the facility used to conduct the simulation, the motion conditions simulated, the overall run schedule followed, and the typical daily work/rest routine of the subjects during the formal experiment runs. The reader is also referred to:

- Volume 1, "Summary Report," (Ref. 1) for an overview of the program and results.
- Volume 3, "Visual-Motor Tasks and Subjective Evaluations," (Ref. 2) for a detailed description of a group of tasks and measures under the responsibility of Systems Technology, Inc.
- Volume 4, "Crew Cognitive Functions, Physiological Stress and Sleep," (Ref. 3) for a detailed description of a group of tasks and measures under the responsibility of Human Factors Research, Inc.
- Volume 5, "Clinical Medical Effects on Volunteers," (Ref. 4) for complete data on crewmen, incidences of motion sickness, medical logs, and effects.

This volume is organized in the following fashion. Section II covers the experiment facility, including the motion generator system and the layout of all the apparatus associated with the tests. Section III details the measured simulator motions and compares them with those selected for simulation. Section IV summarizes experiment test schedules.

B. BACKGROUND

The Phase II simulation is part of an ongoing series of experiments whose general scope is the investigation of the implications of 2000T

Surface Effect Ship (SES) rough water/high speed motion on crew habitability and performance. During the first program and phase in 1973, nine naval SES crewmen from the Surface Effect Ship Test Facility (SESTF) at Patuxent, Maryland, were first put through an exploratory sequence of simulations at NASA's Marshall Space Flight Center (MSFC Simulation). These were designed to evolve tasks and procedures and to establish motion condition/run length combinations of greatest interest, for use in subsequent experiments (Refs. 6 and 7). Phase I included continuous exposures, lasting from 1/2 to 4 hours, to simulated motions calculated from a mathematical model of a generic 2000T SES for starboard bow (sea from 135 deg) Sea States 3, 4, and 5 traversed at 80, 60, and 40 kt, respectively (henceforth abbreviated as SS 3/80 kt, etc., or simply SS 3, SS 4, and SS 5). Having been able to tolerate the most severe of these conditions for 4 hours in Phase I, the same four crewmen from the Phase I simulations then (Phase IA) underwent 36 to 48 hour simulator runs of the SS 3/80 kt condition and then of either the SS 4/60 kt condition or a "half-amplitude" SS 5/40 kt condition (command input to the motion simulator attenuated by 50 percent to crudely simulate ride control effects). As summarized in Ref. 6 and reported in detail in Ref. 7, these SESTF crewmen adapted gradually to the somewhat unusual motion environment, learning to accommodate normal life support functions such as eating, drinking, moving about, and sleeping. They could perform with varying degrees of success all of the tests in a battery of simplified (but operationally relevant) tasks, such as navigation plotting, cryptography, auditory vigilance, lock opening, keyboard operations, tracking, and equipment maintenance and repair. Although there was some evidence of general muscle and eye fatigue due to the continuous motions, performance did not show pronounced dropoffs with time over the 48-hour (maximum) periods tested.

There were two main shortcomings of the Phases I and IA tests from their outset: 1) the very small sampling of well-motivated crewmen made it difficult to generalize the results to a wider population; and 2) the existing ONR/HFR Motion Generator (MoGen) could not adequately replicate the higher acceleration and velocity portions of the commanded motion

waveforms with the larger Phase IA cab (which had eating, sleeping, and lavatory facilities for two persons, suitable for long runs). Accordingly, the Phase II simulation was planned with the goal of overcoming these deficiencies:

> "1. The primary objective of the Phase II Simulation Program is to increase and improve the available data base on the effects of predicted 2KSES motion environments on the performance and health of humans."

and, secondarily, to obtaining a more complete understanding of observed results:

> "2. Secondary objectives of the program are:
>
> 2.1 to improve understanding of the relationship between particular characteristics of the predicted environment and the observed or measured effects on volunteer subjects.
>
> 2.2 to improve understanding of the contribution which adaptation processes may play in determining the acceptability of motion environments."

To meet these objectives, the motion generator system underwent extensive modifications in April-June 1975 prior to the beginning of the Phase II tests. The upgraded facility and resulting system capabilities are summarized in the following section. (A more detailed account of motion generator modifications is presented in Ref. 8.)

SECTION II

EXPERIMENTAL FACILITY

The experimental facility used in these Phase II tests is located in Goleta (near Santa Barbara), California. It included:

- The ONR/HFR Ship Motion Generator (nicknamed "MoGen") upgraded in performance specifically for Phase II.
- Two almost-identical cabs, one moving and the other stationary, in which two pairs of crewmen underwent simultaneous tests.
- Various motion control and test apparatus in an adjacent Control Room.

This section will describe those aspects of the facility which were common to all the tests and agencies involved in Phase II. Special test apparatus used by each investigator are described separately in the appropriate other volumes of this series (Refs. 2, 3, 4).

A. MOTION GENERATOR

1. General

The ONR/HFR Motion Generator has been gradually developed, over several years, from its original role in simulating the motions of a stationary floating vehicle in large sea-swells (Ref. 11) to a very high-fidelity, wide-band 3 degree-of-freedom device capable of simulating the motions of high-speed ships operating in rough seas (Refs. 12, 13). Its heart is a modified hydraulic elevator drive which pushes a roughly 2-ton carriage-plus-cab up and down rails on a 30 ft tower. The cab is pivoted in two axes below the floor to provide combined pitch (plus surge) and roll (plus sway) motions. Its 8 ft × 8 ft × 7.5 ft dimensions provided ample room for two crewmen and the necessary test apparatus. The ONR/HFR MoGen is relatively simple, reliable, and failsafe compared to many other higher acceleration devices, and has uniquely large stroke and velocity capability.

2. Performance

As upgraded, the MoGen has a vertical stroke of 20 ft (±10 ft in heave amplitude) and can achieve ±1.0 g accelerations at frequencies from 0.3 to over 3.0 Hz. It also provides roll and pitch motions of up to ±15 degrees, matched in response to the heave motions. Further details of its demonstrated Phase II performance capabilities are listed in Table II-1.

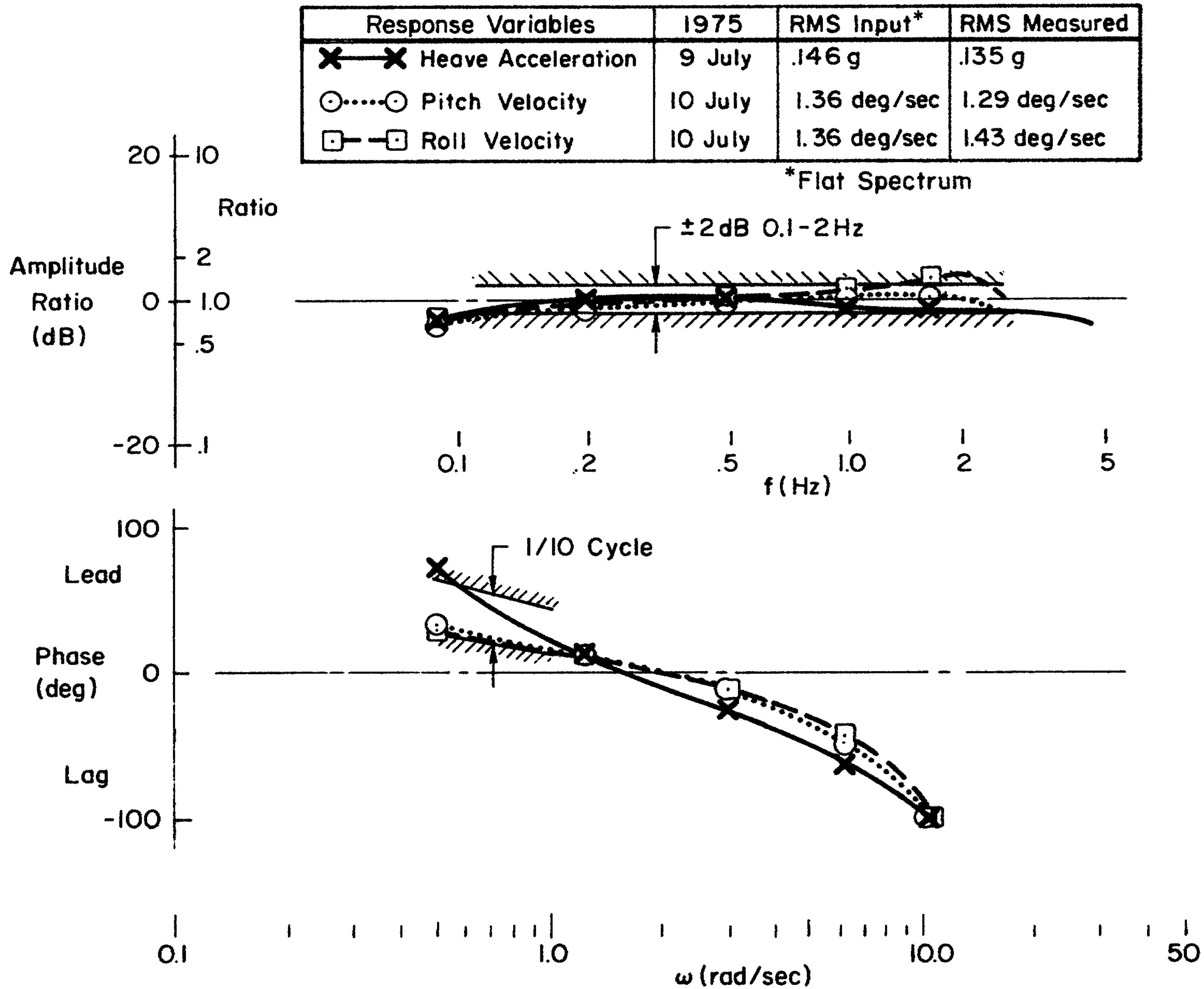
It should be noted that for sinusoidal inputs, the heave velocity limit of ±18 ft/sec occurs at the intersection of the position and acceleration limits, which all occur at about 0.3 Hz, so velocity is not a limitation over the usable performance range. This is an important MoGen advantage over many other large motion generators used for aircraft simulation, whose intrinsic velocity limits of ±2-4 ft/sec severely restrict their ability to simulate high-speed-ship motions (e.g., the facilities used in the earlier tests in this SES development at NASA/Marshall Space Flight Center, Ref. 14).

For various reasons, the basic commands to the motion generator axes are acceleration in the heave axis and angular-rate in the roll and pitch axes. The upgraded heave motion system has a very fast acceleration response over the frequency range from 0.2 to 5 Hz, being characterized by a flat amplitude and a 0.02-0.03 sec effective delay between commanded and measured acceleration. However, the pitch and roll systems have longer response times, so the heave system is lagged to match them as described later herein. Typical frequency responses to a quasi-random input signal of each axis are given in Fig. II-1. The commands were the sum-of-five-sinusoids, at the frequencies shown, all of equal amplitude (i.e., a "flat" amplitude spectrum), and the responses were analyzed over 100 sec intervals. Over the 0.1 to 2+ Hz measurement range, the response amplitudes follow inputs within ±2 dB (+20 percent) while the phases are generally matched between each degree of freedom within less than 1/20 cycle. Somewhat larger phase mismatch occurs at frequencies below about 0.15 Hz, where the "washout" circuitry used to keep the cab centered against drifts causes phase lead in each axis, most pronounced in heave. Nevertheless, these well matched responses imply that the pitching motion

TABLE II-1

VERIFIED MOTION GENERATOR PERFORMANCE (1975)

HEAVE:		
Limits:	Position	± 10 ft
	Velocity	± 18 ft/sec
	Acceleration	+ 1.0+ g (up), −0.9 g (dn)
Usable Bandwidth		0.1 to 5 Hz
Small-Signal Deadband		±0.04 g (0.1-5 Hz)
Effective Delay to Acceleration Commands		0.02 sec (minimum) 0.18 sec (Matched to roll and pitch axes)
Harmonic Distortion		
(Average over 20-80% Amplitude, 0.2 – 2.0 Hz)		< 10%
Overall Linearity (rms g's)		> 0.95
PITCH AND ROLL:		
Limits:	Angle	± 15 degrees
	Rate	± 25 deg/sec
	Acceleration	± 150 deg/sec^2
Bandwidth		0.1 to 4.0 Hz
Effective Delay		0.18 sec
Overall Linearity (rms rate)		> 0.95
Cross-Coupling Pitch/Roll		< 8%
Phase Matching to Heave (0.2-3.0 Hz)		< 1/20 cycle (< 20 deg)



Response Variables	1975	RMS Input*	RMS Measured
Heave Acceleration	9 July	.146 g	.135 g
Pitch Velocity	10 July	1.36 deg/sec	1.29 deg/sec
Roll Velocity	10 July	1.36 deg/sec	1.43 deg/sec

*Flat Spectrum

Figure II-1. Motion Generator Frequency Response at Start of Phase II

transient which accompanies an SES's drop from a large wave and subsequent bow-up slam, are realistically reproduced by the McGen.

Time traces and detailed statistics of the actual motions, showing the excellent reproduction of various prerecorded sea states, are given later in Section III.

3. Heave Drive System

The heave motions are produced by an extensively modified hydraulic passenger elevator drive (see Refs. 7 and 12 for details). A functional schematic of the Phase II version is given in Fig. II-2, and a block diagram of the heave control system is given in Fig. II-3. A brief explanation of its operation is helpful in understanding the limitations on performance and the factors responsible for some of the operating problems described later herein.

a. Power Supply

Referring to Fig. II-2, start with the main pumps which were upgraded for Phase II to two 100 horsepower constant-flow-rate gear-pumps with a maximum pressure of 1000 psi. This constant volume flow passes normally closed (NC) bypass valves set to return any flow over 850 psi, and normally open (NO) check valves which prevent back flow. The bulk of the 500 gal/min flow is directed via 4 in. pipes through a servo-actuated four-inch-diameter "bypass flow control valve" to the 1000 gal reservoir located above the pumps.

b. Flow Control Valve

The large pressure drop of the constant-flow-rate oil past this precisely positioned flow-control valve produces the required back-pressure elevator cylinder and roughly 10 in.^{2} ram to maintain or change the height and acceleration of the moving carriage-plus-cab. This pressure drop, which averages from 300-400 psi to balance the 3000-4000 lb cab weight, heats the oil, which is then returned by a 6 in. pipe to the reservoir for cooling. If the cab is to go up, the flow valve is shut down in proportion to the acceleration required, thereby forcing oil into the

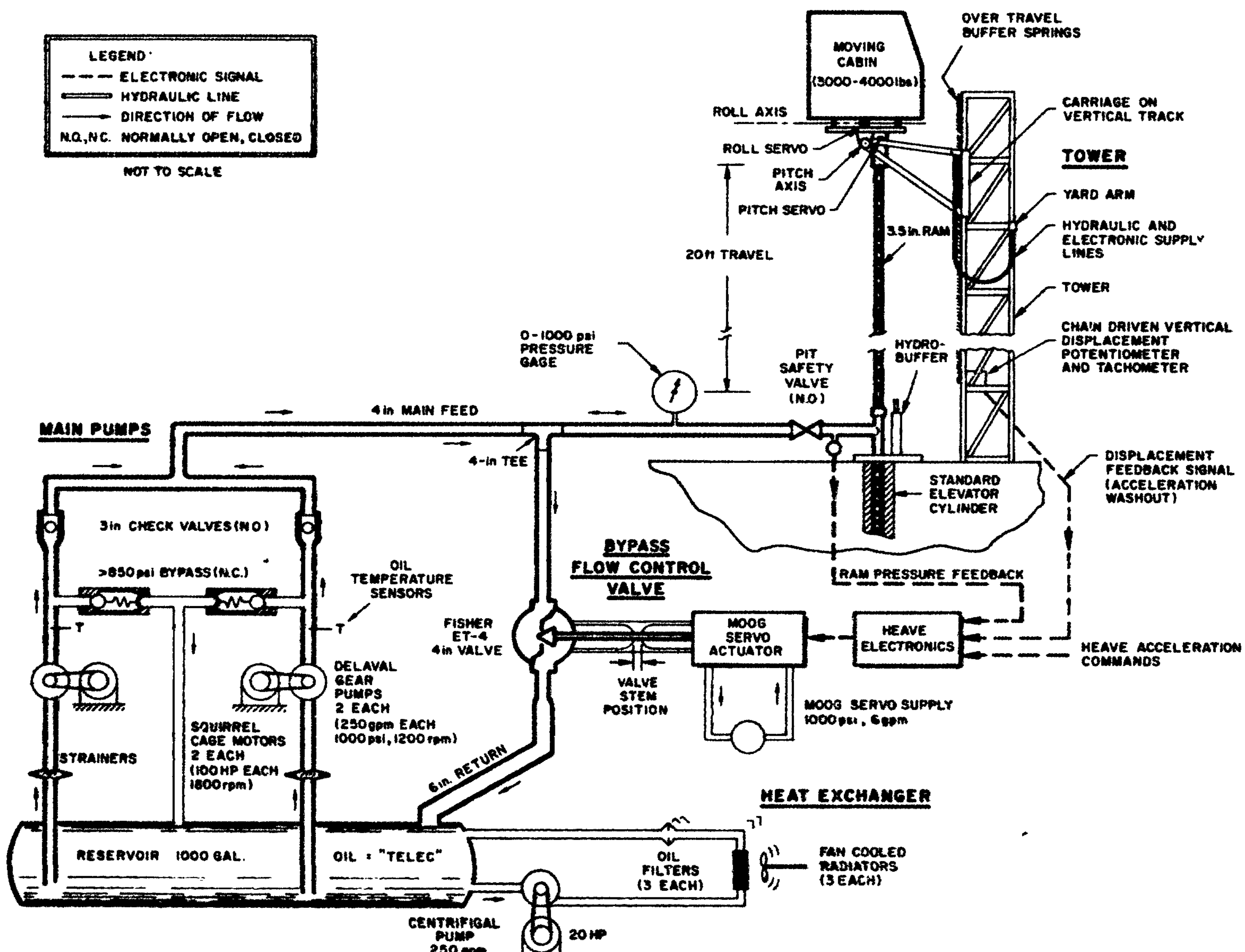


Figure II-2. ONR/HFR Motion Generator Heave Drive Hydraulic System Functional Schematic

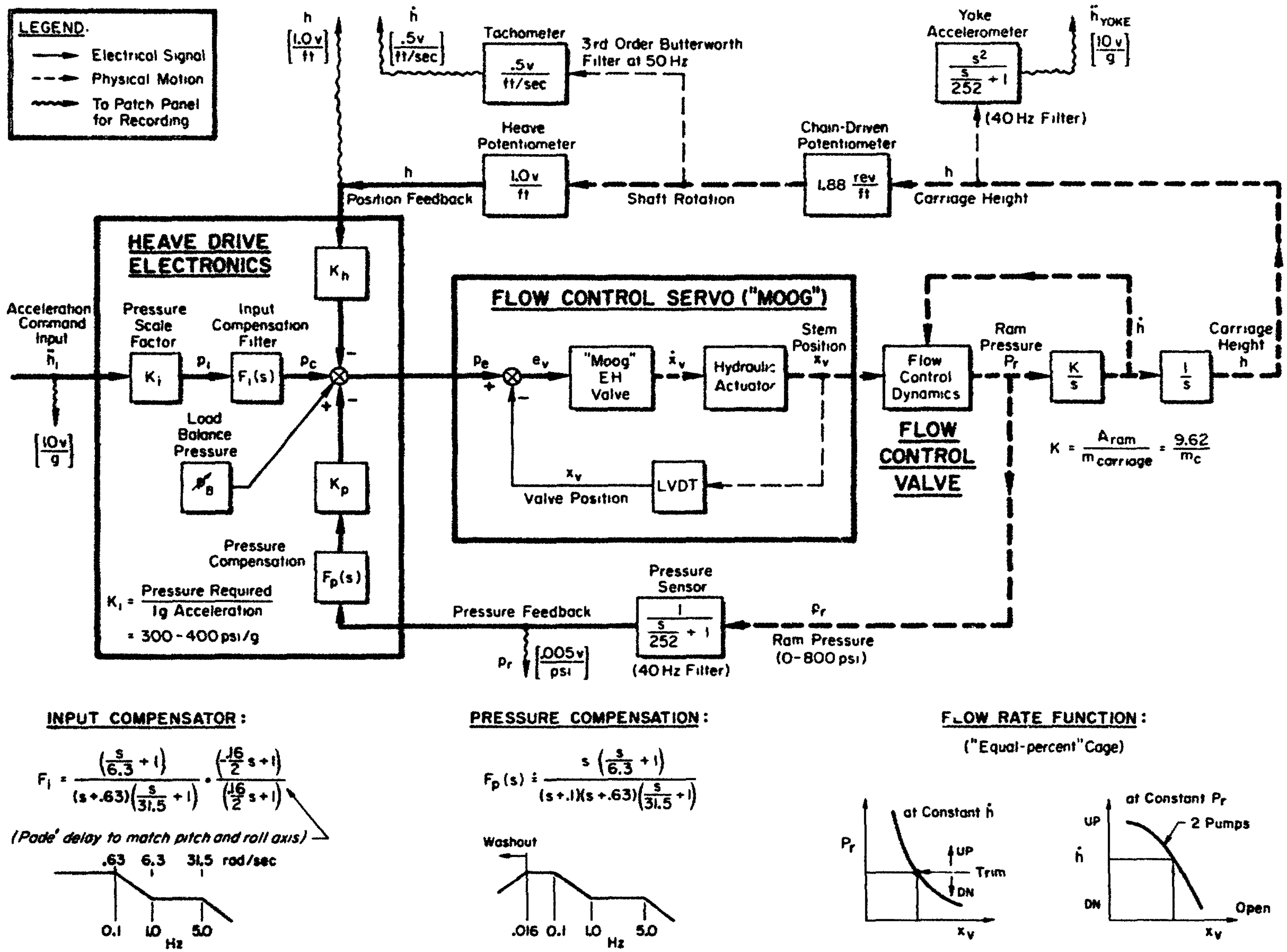


Figure II-3. Block Diagram of Heave Motion Control System (Phase II)

cylinder. The maximum upward acceleration is set by the ratio of maximum pump pressure (here set at 850 psi) to the balance pressure. The downward acceleration is limited to a nearly free-fall, with the valve fully open. The upward velocity is limited to the maximum flow rate of one or two pumps, with the valve fully closed.

c. Cooling System

Roughly 40 percent of the pump's maximum power is absorbed by the constant pressure drop across the flow control valve, and the oil is heated in being raised to this pressure. Consequently, much heat (power) must be continuously dissipated by the cooling system. (This inefficiency is the price paid for the simplicity and safety of this drive scheme.) A separate, low-pressure 250 gal/min pump recirculates the hot reservoir oil through three fan-cooled radiators. The cooling system operates intermittently (controlled by a thermostat) to keep the oil temperature between 120-140° F, for which viscosity bypass valve operation is optimum. This cooling system has marginal performance, such that on hot days (over 85° F) it must run continuously. If oil temperature exceeds 140° F, thermal runaway can occur. To extend the MoGen operating limit beyond such temperatures the reservoir shell is cooled by a water-film system. Even with this provision, the limited capability of the new cooling system, combined with hot weather (which reduced the cooling-radiator capacity and heated the reservoir drum), led to frequent thermal overloads and shutdowns. Some one-pump operations, in which the same pressure drop is maintained at one-half the flow rate, hence one-half the heat load, were tried for those low-motion conditions where the resulting lower maximum velocity would not distort the waveforms. These instances are noted in the run schedule shown later.

d. Motion Control System

Refer now to Fig. II-3, which is the block diagram of the new heave motion control system, extensively modified just prior to Phase II. The "heave control electronics" accepts height acceleration commands from an

external source (e.g., recorded tapes), and converts these to ram pressure commands via the scale factor* K_i and compensation shaping filter $F_i(s)$. This filter compensates for the closed-loop dynamics and introduces a pure time delay of 0.16 sec (Pade approximant) to match the faster heave closed-loop response to the slower pitch and roll responses. The load balance control trims the mean pressure to exactly balance the cab weight. The basic feedback is ram pressure as measured near the elevator cylinder (at the pit safety valve). Cab height, measured by a chain-driven potentiometer is fed back at low gain to provide an acceleration washout (in effect a weak centering "spring") to prevent acceleration errors from causing cab drift.

The flow-control-valve is operated by a very fast and powerful hydraulic position servo, having its own 1000 psi power supply and very tight position control loop. It can position the 4 in. valve to within less than 0.001 in. over its 1 in. usable stroke. This fast servo, plus precise pressure measurement and feedback compensation circuits, together result in a closed-loop pressure response having a 5+ Hz bandwidth, this limit being primarily imposed to prevent excitation of structural modes at 7 Hz or more (The 2.4 Hz cab angular modes are actively damped; see below.).

At the bottom right of Fig. II-3 are sketches of the flow and pressure relationships of the flow-control-valve. There are some nonlinearities here which can produce slight waveform distortion at high slew rates, but these are minimized by the "equal-percent" valve opening schedule, which changes the valve opening by equal percentages of its trim opening for given small position changes, regardless of the trim value. This also permits operation with one pump (at half the flow rate and half the trim opening) without a change in the electronic circuit gains.

Also noted in Fig. II-3 are the locations and sensitivities of the motion measuring transducers, shown by the wiggly arrows. The vertical accelerometer is located on the yoke just above the ram, so it reads

---

*Note, this scale factor is the ratio of total moving mass (cab + carriage + ram + crew) to piston area (9.60 in.^{2}). Failure to correct for crew weight led to some problems early in Phase II.

vertical acceleration independent of cab pitch or roll, but it does not pick up any structural compliance effects between the yoke, the gimbals and the cab floor.

Various calibration tests and fine-tuning adjustments were made just prior to Phase II (Ref. 15). It was shown that best results occur for random acceleration spectra in the 0.3-2.0 Hz range, with as little power as possible below 0.2 Hz, where washout-imposed phase lead distorts the waveform fidelity somewhat. The excellent heave motion fidelity achieved by the MoGen in these tests is illustrated later in Subsection III-C.

4. Roll and Pitch Drives

The roll and pitch drives are high-performance aircraft-type electro-hydraulic position servos which give a closed-loop (first-order response) time constant of $T \doteq 0.5$ sec to position commands. Due to compliance in the mounting of the gimbals and/or actuators, there are structural resonances in the pitch and roll axes. The "pitch" gimbal (which moves toward and away from the tower) is the most compliant and had the lowest resonant frequency ($f_n \doteq 2.2$ Hz, with $\zeta_n \leq 0.07$), while the roll gimbal (transverse to the tower) had less resonant properties ($f_n \doteq 4.0$ Hz with $\zeta_n \doteq 0.10$). The damping of these natural structural resonances was further reduced by the position feedbacks. In Phase IA they had given rise to annoying oscillations which had to be eliminated by bracing out the roll and pitch motions. During the facility upgrade for Phase II, STI developed active structural-mode dampers consisting of filtered gimbal angular acceleration (Ref. 16). These very effectively (and weightlessly) attenuated the residual motions in roll and pitch and allowed compensation of the system to achieve angular rate command bandwidths, ranging from 0.1 to greater than 2 Hz, with an effective delay of about 0.18 sec.

For a more detailed account of the MoGen heave, pitch and roll dynamics, see Refs. 7, 12 and 15.

B. INPUTS, OUTPUTS, AND INTERCONNECTIONS

1. Inputs

A simplified block diagram showing the various alternative inputs to, and outputs from, the MoGen during Phase II is given in Fig. II-4. Solid lines depict the main signal flows, while the dotted lines and circles identify recorded outputs.

The "external oscillator" and "Describing Function Analyzer" (STI Model DFA-1) were used mainly during calibrations done just prior to, and occasionally during, Phase II. The latter provided a sum-of-randomly-phased-sinusoids of frequencies: 0.08, 0.20, 0.48, 1.0 and 1.67 Hz, each with adjustable amplitude. The "mag tape" is an HFR backup FM Analog system, often used for kinetosis testing.

The primary input for Phase II was the "NSRDC Disc", a digital-to-analog system on which detailed calculated motions for the 2000 Ton SES had been recorded at 20 samples per second. (Detailed descriptions of the command signals are given in Section III.) The sampled-and-held signals for heave acceleration ($\ddot{z}$), pitch rate ($\dot{\theta}$), and roll rate ($\dot{\phi}$) were "conditioned" by a set of the NSRDC 6-pole Butterworth filters having a break-frequency of 6 Hz, to remove the step-like nature of the sampled commands prior to being sent to the MoGen. Because the SES waveform is highly asymetric (higher upward acceleration peaks, offset by longer downward ones) the smoothed $\ddot{z}_i$ signal was inverted to the $\ddot{h}_i$ MoGen command.*

2. Outputs

The outputs were recorded on a variety of media. For on-line monitoring of the MoGen motions, selected motions were continuously plotted on an 8-channel pen recorder at slow chart speed. These channels were, in order:

---

*Throughout this volume, vertical motions are defined as positive up in concordance with established HTR MoGen sign conventions, and are designated by the symbols h, $\dot{h}$ and $\ddot{h}$ — for height displacement, velocity, and acceleration, respectively — to avoid confusion with the conventional ship motion z-axis which defines heave motion as positive downward. Nevertheless, the scalar rms vertical acceleration is still termed σ_{a_z} or g_z for convenience.

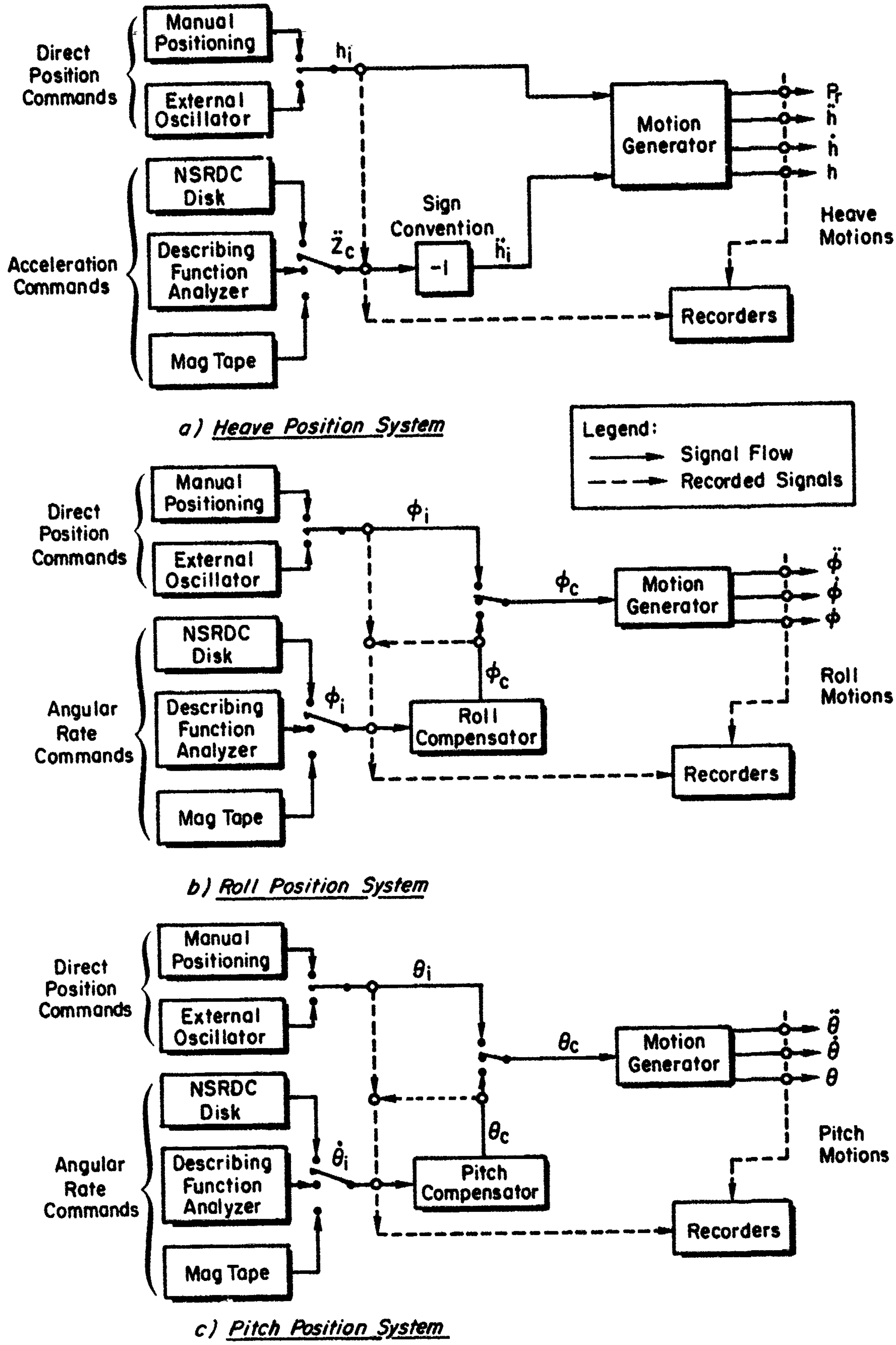


Figure II-4. Inputs and Outputs of the MoGen During Phase II

1) commanded heave acceleration, $\ddot{h}_i$; 2) (measured) heave acceleration, $\ddot{h}$; 3) heave velocity, $\dot{h}$; 4) heave position, h; 5) pitch rate command, $\dot{\theta}_i$; 6) pitch rate, $\dot{\theta}$; 7) roll rate command, $\dot{\varphi}_i$; and 8) roll rate, $\dot{\varphi}$.

These and other test data signals were also recorded intermittently on 16 channels of the NSRDC analog digital recording system. This system had the capacity to record 64 channels of data with an input signal range of ±10 volts DC. All inputs are filtered with six-pole Butterworth low-pass filters to prevent aliasing due to sampling. The cutoff frequency of these filters was adjusted to 6 Hz. The filtered signals were converted to floating point binary numbers on an Analogic Model 5800 A-D converter at a sampling rate of 20 per second. The converted data were written onto a magnetic tape twice per second by a Kennedy Model 8109 nine-track digital tape recorder. One digital tape provided approximately one hour of continuous recording.

The MoGen motions were recorded about every hour near the beginning, and every four hours near the end, of the program.

Along with NAMRLD's own test outputs, some of the motion signals were also recorded on the NAMRLD FM tape recorder (in fact, these were used for much of the motion data analysis presented in Section III because of undetected, intermittent, power-supply failures in certain A/D channels of the NSRDC system).

3. Interconnections and Scale Factors

Figures II-5a, b, c are the definitive signal flow diagrams for the Phase II tests, showing the key scale factors and interconnections. In general, the portions in the center were located in the HFR electronic cabinet beside the MoGen console. Peripheral signals were patched from or to other locations (designated by the symbol) via the HFR patch bay on the cabinet. Whenever possible the same scale factors were used throughout the test to facilitate data handling.

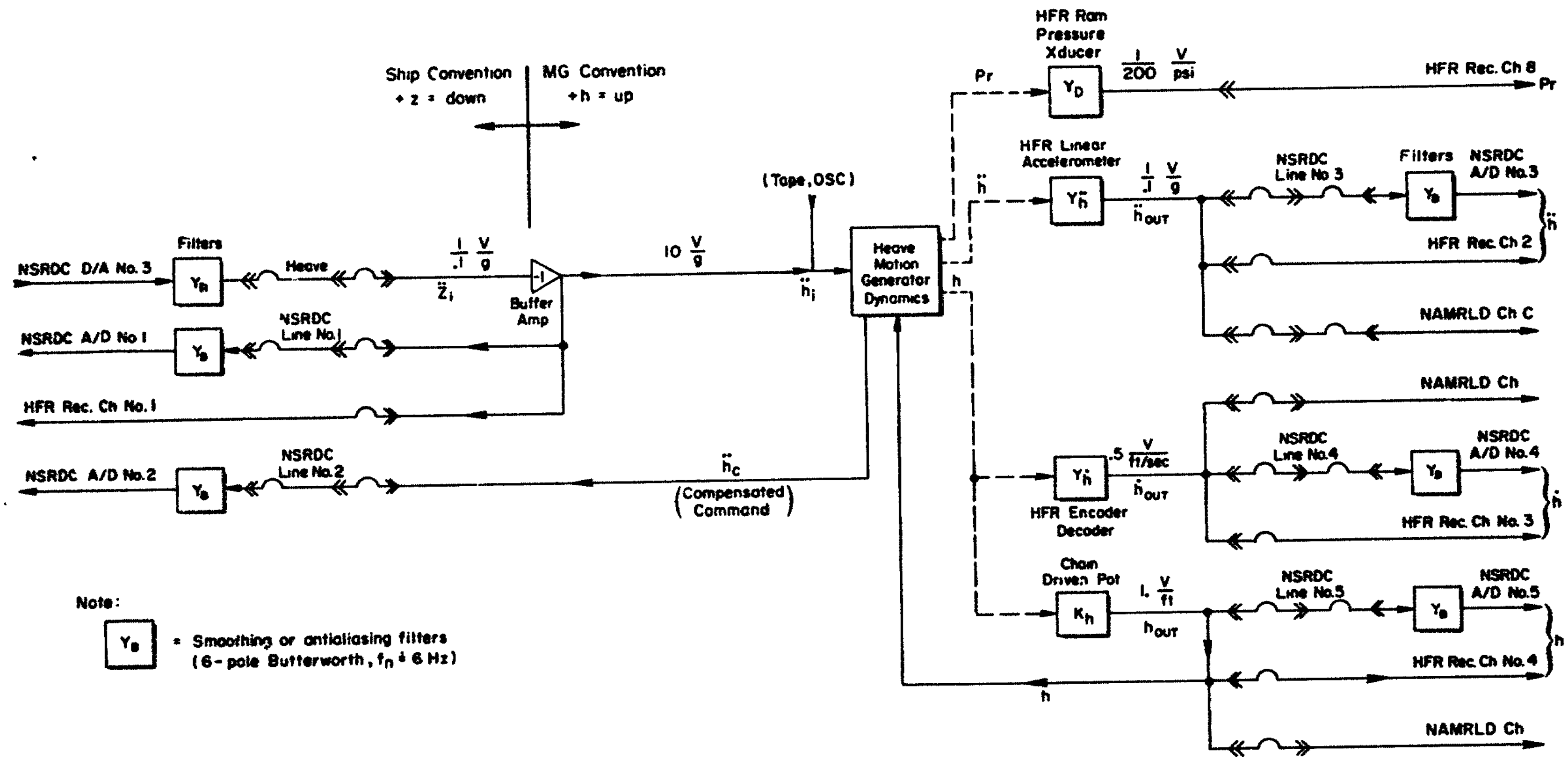


Figure II-5a. Heave Signal Interconnections and Scale Factors

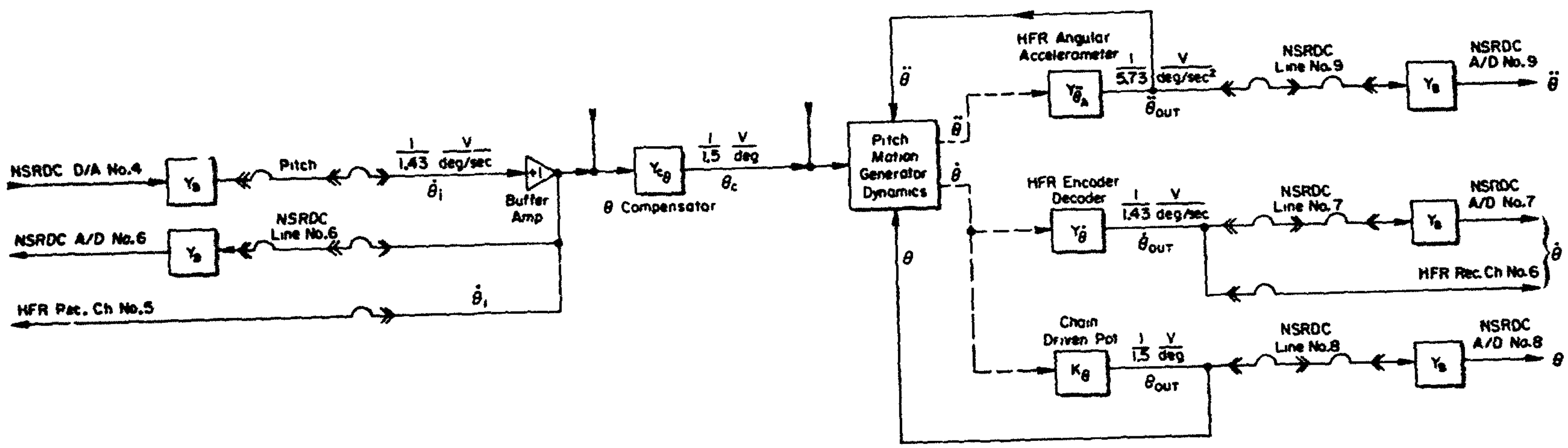


Figure II-5b. Pitch Signal Interconnections and Scale Factors

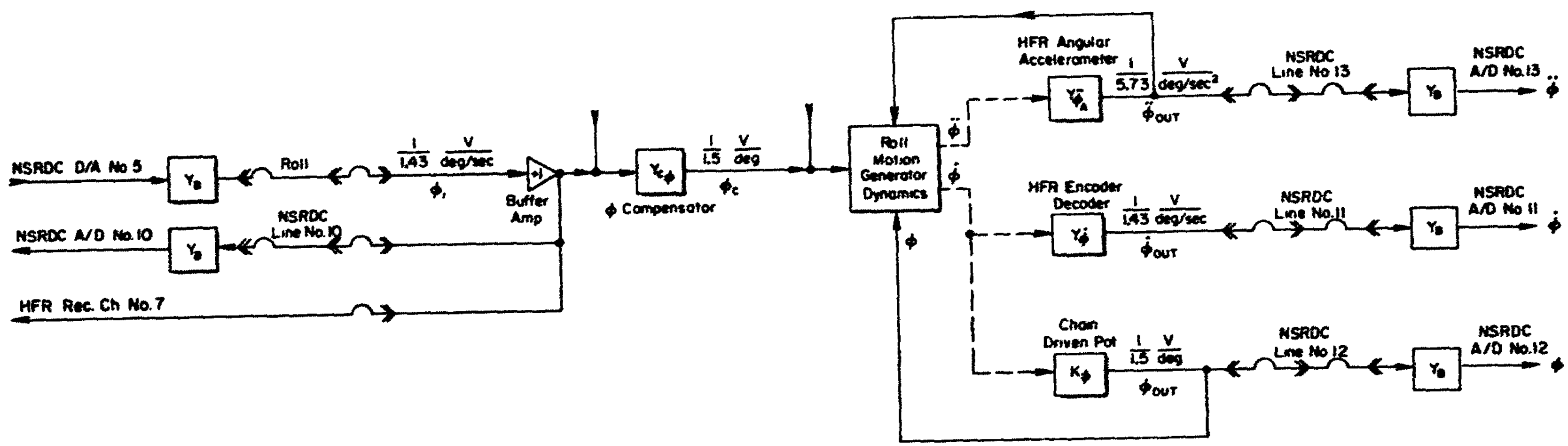


Figure II-5c. Roll Signal Interconnections and Scale Factors

C. CONTROL ROOM

The Control Room is adjacent to the Motion Generator and contains the consoles for controlling and monitoring the MoGen, performance measurement equipment, and the audio-visual monitoring system. Figure II-6 shows its layout for the Phase II tests.

The communications and task monitoring console contains the closed-circuit TV for monitoring the interior of the moving cabin (5), the audio communication system for interaction between the motion crew and ground crew personnel (6), and the task administration equipment. The Task Conductor (B) is stationed at this console (4).

The Motion Generator operating panel (8), compensators and patch panel (9), and strip chart recorders (10) are located adjacent to the communication console. The Motion Generator Operator (C) is stationed at these consoles. (Reference 1 contains pictures of Task Conductor and MoGen Operator Station consoles.)

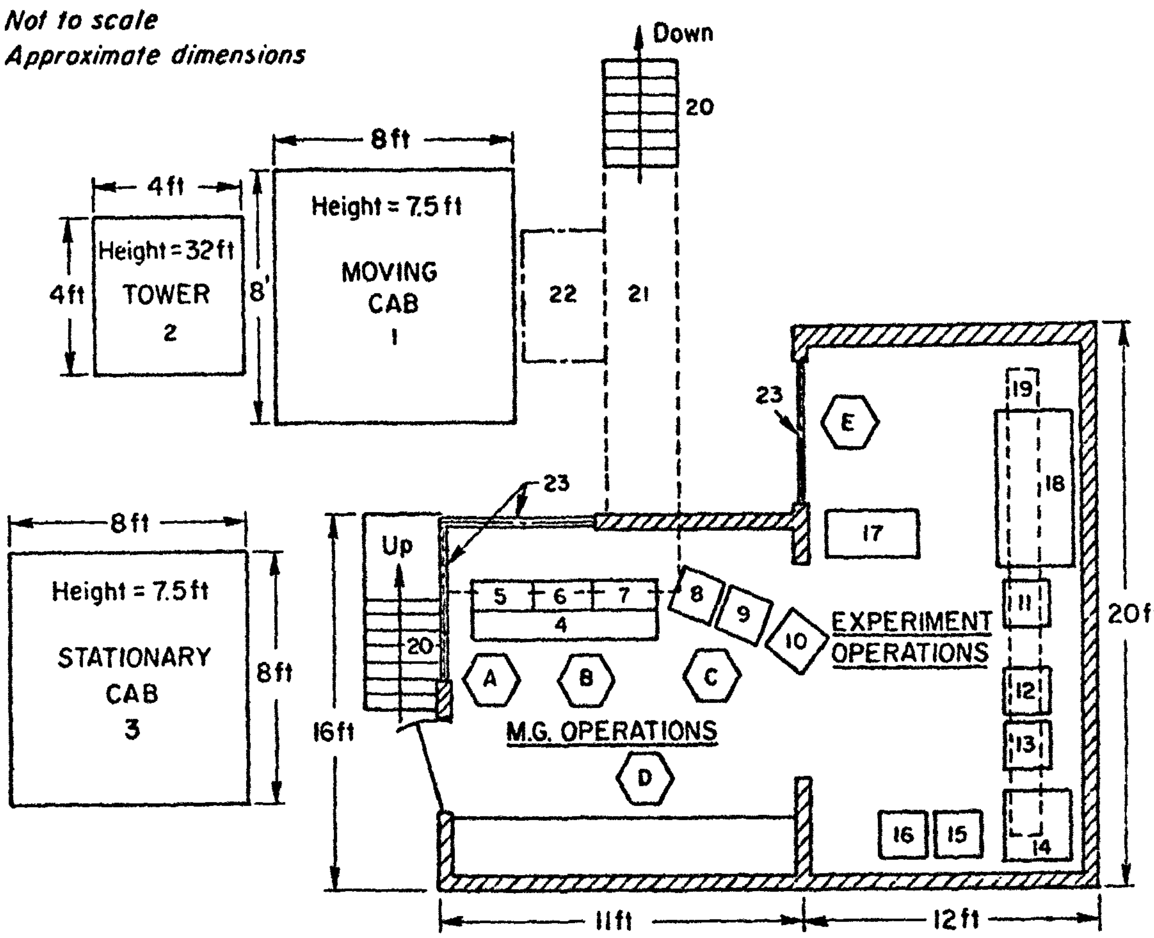
The "STI Task Panel" (7) contains the instrumentation for measurement of the "ECM Tracking," and "Lock Opening" Tasks. The Describing Function Analyzer is also located near this panel. The NSRDC digital computer system (12), (13), and (14), is patched to the Motion Generator via the Patch Panel.

The locations of the Medical Monitor (A), Test Director (D), and Observer stations (E) are as noted in Fig. II-6.

The Control Room is air conditioned for the necessary cooling of all electronic equipment. Ample window areas provide ground crew personnel and observers with a view of the external Motion Generator equipment in operation.

D. CABINS

The Static and Moving Cabins were nearly identical in layout, and the interior cabin arrangement common to both is depicted in Fig. II-7. Duty Station I, where ECM Tracking, Maintenance, Keyboard, Lock and Cryptographic Tasks were performed, was located at the workbench below



LEGEND

1. Moving Cabin
2. Tower
3. Stationary Cabin
4. Communications and Task Monitoring Console
5. Voice Tape and Controls
6. Voice and T.V. Monitors
7. STI Task Panel
8. Motion Generator Operating Panel
9. Motion Generator Compensators and Patch Panel
10. Strip Chart Recorder
11. HFR Computer
12. NSRDC Digital Tape Recorders
13. NSRDC Digital Computer
14. NSRDC Disk Drive
15. NSRDC Teletype
16. NSRDC Line-Printer
17. NAMRLD Strip Chart Recorder
18. NAMRLD Equipment
19. Air-Conditioning Duct (Under Floor)
20. Stairs to Docking Ramp
21. Overhead Walk-way
22. Docking Ramp
23. 5 ft Wide Observation Windows

A. Medical Monitor
B. Task Conductor
C. Motion Generator Operator
D. Test Director
E. Observer/Support Personnel

Figure II-6. General Arrangement of the ONR/HFR Motion Generator Facility (Phase II)

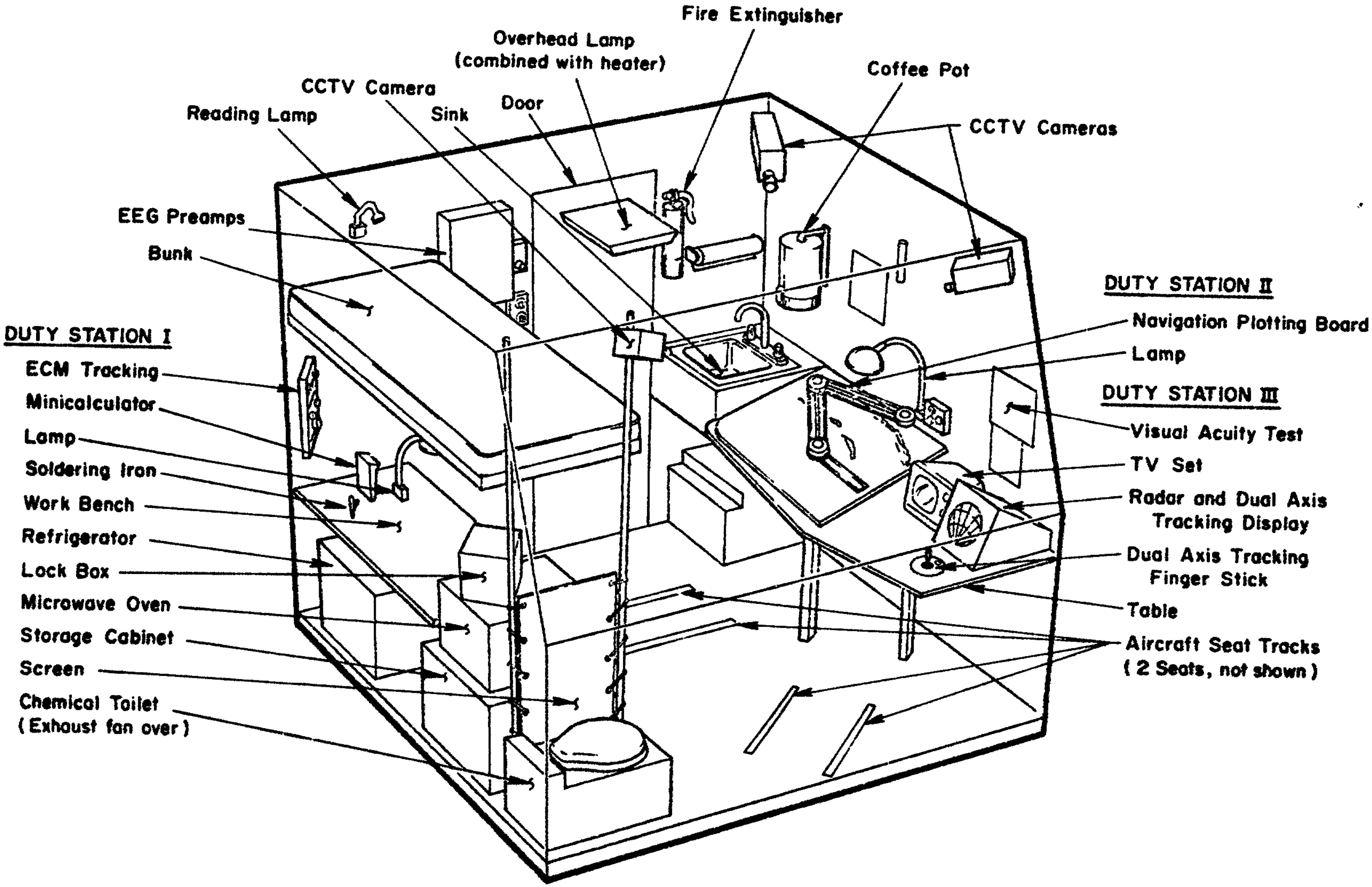


Figure II-7. General Arrangement of Apparatus in Cabin for Phase II

the sleeping bunk; and Duty Station II, at the large board used for Navigation plotting. A set of deck rails between these two stations permitted a swivel seat to be moved and locked in a direction in accord with the duty schedule. A second seat, also adjustable each 45 deg in azimuth, was located on a fixed base at Duty Station III in the port quarter of the cabin. (See Fig. II-8 for precise seat location geometry.) The Missile Detection and Collision Avoidance Radar tasks and the Dual Axis Tracking task were done at this station, which was also equipped with a broadcast TV, with earphones, for leisure-time viewing.

Frozen prepared meals stored in the refrigerator beneath the Duty Station I bench were cooked in the microwave oven beneath the foot of the bunk. Hot water for mixing with dehydrated beverages was available in the electric coffeepot attached to the wall above the sink, which provided cold running water. A refuse container was located on the inside of the door, and a chemical toilet at the foot of the bunk was vented outside the cabin.

TV cameras were arranged so that one scanned the forward and the other the aft duty stations. For exchanging lightweight items with the cabin in motion (e.g., the mail-drop and data-sheets), a duffle bag could be lowered by a "dipping line" to the ground crew and retrieved through a trap door at deck level forward of the cabin door.

Ample illumination for desk work and reading was provided by lamps at each duty and rest station to supplement the overhead cabin lamp. Heaters and air conditioning controlled by the crew maintained a shirtsleeve environment of about 70-76° F (21-24° C).

The noise level in the moving cabin was dominated by the nearby MoGen pumps and hydraulic vibrations transmitted by air and structure to the cabin. Measurements of ISO: A-weighted broadband noise showed all parts of the cabin to have the same level within ±2 dB-A. The overall noise level with all pumps operating was about 71 dB-A in the moving cab and 69 dB-A in the stationary cab.

A per-octave-spectrum-scan showed broadband distribution of noise over the 31.5-4000 Hz range, with a maximum of about 80 dB near the 63-125 Hz region.

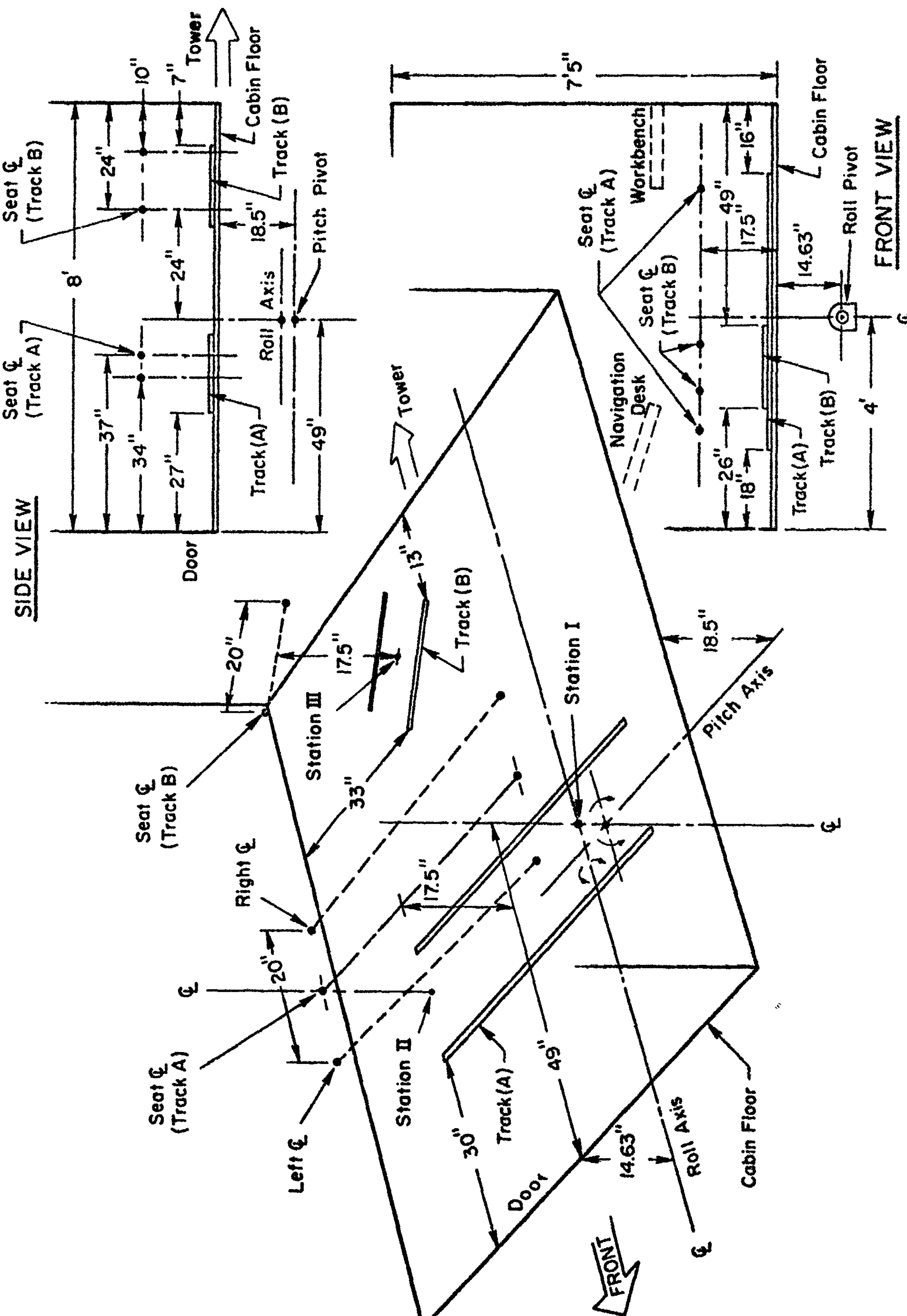


Figure II-8. Seat Locations, Phase II

In summary, the living conditions in these cabins were cramped but not too unpleasant in ambient temperature and noise level. Experienced observers noted that similar conditions existed in a number of shipboard or airborne situations.

SECTION III

CHARACTERISTICS OF MOTION CONDITIONS

A. SELECTION OF MOTION CONDITIONS

1. Test Objectives and Implications

As previously stated, the objectives of the Phase II simulation were to increase and improve the data base on the health, comfort, and performance implications of 2000 Ton SES motion environments, and to gain additional insight into the relationships between specific motion characteristics and resulting motion effects. In addition to requiring a larger and more diverse subject population than Phase IA, these objectives imply that the simulated motion conditions must closely approximate those of a typical SES and that they must be analyzed in sufficient detail to identify those motion properties which distinguish one condition from another. These goals also demanded a more formal matrix of test conditions than needed for Phase IA. The first of these requirements was met by faithfully reproducing the best available calculated motions for the typical 2000 Ton SES. The preceding section describes the current capabilities of the MoGen which was upgraded just prior to Phase II to meet the first requirement. These capabilities are demonstrated later in this section as is the detail with which the simulated motions were analyzed. As described below, adherence to a formal design proved the most difficult requirement to meet.

2. Experiment Design

Phase IA tests had demonstrated that motivated SES crewmen (with at sea experience) could adapt to motions somewhat similar to those expected at the center of gravity of a typical 2000 Ton SES traveling at 60 kt in starboard bow Sea State 4 and that they could tolerate such motions for continuous periods as long as 48 hours. However, the limited performance capability of

the MoGen in Phase IA resulted in appreciable attenuation of the peak accelerations and distortions of the spectrum (i.e., from 0.25 g commanded to 0.19 g measured).

To meet Phase II objectives within the limited time and budgetary requirements dictated by PMS 304 priorities, the test plan originally provided for 12 subjects, run in two-man crews, two crews per test-session-team, for 3 test sessions — see Subsection IV-A for details. Two day (48 hr) exposures were to be run with five conditions: Full SS 3/80 kt, SS 4/60 kt, and SS 5/40 kt conditions, as well as SS 4A and SS 5A cases with heave acceleration waveforms attenuated to the same rms G_z as SS 3 (0.194 g). Their characteristics are described in succeeding subsections. The conditions were to be presented in order of ascending rms G_z to facilitate new adaptation to motion and to minimize loss of data due to adverse subject reaction to these motions. Motion runs were to be alternated with stationary runs in a separate but identically equipped nonmoving cabin (shown earlier in Fig. II-1) so that the same work/rest schedule could be followed. These static runs were intended to provide a moving baseline (as subjects learned their tasks) against which to more precisely assess motion effects and to serve as a renormalization period between continuous motion exposures. The former role was especially important for the assessment of motion interference with task performance since total training time on all tasks was limited to a three day period just prior to the first formal run and was generally insufficient for an asymptotic performance level to be reached by most subjects (see Volumes 3 and 4, Refs. 2 and 3, for details).

Following this first experiment, and based on its results, further simulation was to be conducted using the same 12 subjects plus 8 or 9 others to further expand the 2000 Ton SES data base. Circumstances precluded the execution of this initial plan, and the follow-on study was limited to an 8 subject short-run-length mini-experiment designed to provide direct comparison of the <u>waveform</u> effects of the SS 3, SS 4, and SS 5 conditions. Since, at this time, a large number of subject hours had already been logged at SS 3 as compared with SS 4 and SS 5, the second experiment was restricted to the latter conditions, consisting of 6 hr runs at SS 4A, SS 5A, SS 4, and SS 5 in that order. The plan also called for static runs to be interposed

between each motion run, with one (static or motion) run per day per subject pair.

3. Actual Conditions Tested

For a number of reasons, the design of the first experiment was not closely adhered to in the actual tests. To begin with, unexpected motion generator problems arose on the first formal motion run, when hot July weather caused the oil in the heave drive system to overheat, bringing the simulator to a soft stop within the first three hours of the run, which was aborted shortly thereafter. Necessary repairs further delayed the test schedule thus causing a reduction of the planned length of the first two crews' SS 3 exposures to 24 hr. With the overheating problem temporarily solved by passing cold water over the oil reservoir as frequently as necessary to maintain oil temperature below the critical value, the tests continued but not without further alteration of the test design. Neither of the crews could tolerate SS 4 for even 24 hours; as a result, the SS 4 condition was rerun at reduced amplitude and the first team's remaining runs were limited to 24 hr periods.

These variances from the original test design were compounded by an inadvertent change in simulator calibration resulting from the increased gross weight of the fully laden cabin (the calibration having been fine-tuned, on the basis of rms intensity, at a lesser gross weight as the final step in the facility upgrade). The incorrect calibration, which amounted to a reduction in heave acceleration intensity to 80 percent of full scale for the SS 3 condition, was detected and corrected early in August for the second team's test session, but not before that team's two crews had completed runs at a SS 3 condition which had been intentionally attenuated to 80 percent (giving a total attenuation of 64 percent of full scale).

As a result of these and subsequent variances from the original plan occasioned by the inability of a number of subjects to continue with various of the tested conditions for the planned exposure intervals, and by sporadic motion generator problems (which resulted in the premature termination of certain later runs, as well as reducing the heave drive system to one-pump operation for some other runs), several variations of the three originally

selected full scale conditions were run with individual subject exposure times ranging from 30 minutes to 48 hours. As a consequence, actual exposures fell within the original test cell design for only a few subjects. Motion data for each run, including those of the short run experiment, were analyzed and all runs were grouped a posteriori by sea state/speed and, within a given waveform, by the relative attenuation factor used.

It was found possible to group all of the variations mentioned above into a 3 x 3 matrix of which 8 cells were run. The resulting waveform versus attenuation matrix is presented in Table III-1. Test conditions grouped in this manner are henceforth (in the rest of this volume and in the other report volumes) identified by the "Source" tape used to generate them, prefaced by the verbal descriptor of their intensity relative to that of the corresponding source condition, and/or the nominal fraction thereof in parentheses, called "Intensity Level Name" and "Nominal Fraction," respectively, in Table III-1. For example, Low (2/3) SS 3 refers to the upper, left hand cell condition.

The "MoGen run numbers" listed in each cell of the matrix are those used to log all (formal, checkout, et al.) Motion Generator runs as noted in Section IV. The fraction of source condition heave acceleration intensity for each run is given in parenthesis, with the range of such fractions for a matrix column listed in the column headings.

B. SUMMARY OF CONDITIONS SIMULATED

The inputs for the heave acceleration, pitch rate, and roll rate signals characteristic of the three conditions which the MoGen was to reproduce where drawn from the same source tapes used during the Phase IA simulation, Ref. 7. These were the five minute tapes generated by NSRDC using the mathematical model developed by Oceanics, Inc. (Ref. 9) for a generic 2000 Ton SES. As in the previous simulation, continuous motion was generated over the course of each run by playing five minute tape segments head-to-tail, with the "source" signals tapered from zero to their recorded values over the first second of the tape and from their recorded values to zero over the last second to provide a smooth transition.

TABLE III-1

MATRIX OF GROUPED TEST CONDITIONS

Intensity Level Name: Nominal Fraction†: Actual Fraction† Range:	"Low" "2/3" .65-.69	"Medium" "4/5" .77-.82	"Full" "1" .89-.101
Sea State	Month Run	Month Run	Month Run
SS 3/80 kt	(.13g) B July — Aug 483, 485	(.16g) D July 424, 455, 457, C 439,† 440†	(.19g) E Aug 487, 489 Sept 525, 527
SS 4/60 kt	(.17g) F July 453, 454	"SS 4A" (.19g) G Sept 529,* 530,* 532,* 533*	(.25g) H July 446, 451 Sept 540,* 541,* 550
SS 5/40 kt	"SS 5A" (.19g) I Sept 535,* 536,* 538*		(.28g) J Aug 494,† 496† Sept 543,* 545* K 547

Notes:

- ◯ Denotes code for some data presentations; A = static
- ( ) denotes nominal rms G_Z for each group
- †Fraction of source rms heave acceleration
- †Denotes 1-pump runs
- *Denotes 6 hr runs; others typically 20-48 hr

Digital "source" signals, recorded at 20 samples per sec, were converted to analog signals which were passed through a six-pole Butterworth filter having a 6 Hz break frequency to provide actual "command" signals to the MoGen drive system, as described in Section II. The resulting Mogen commands followed the source signals very closely, except that they were limited to ±10 V (±1.0 g) in the digital-to-analog conversion process. Though the smoothing filter attenuated the command spectrum sharply above 5 Hz, the corresponding time signals were not substantially affected since there was very little power in the source spectrum at those frequencies. The command signals and the "measured" motion signals transduced by the MoGen sensors (the latter occasionally exceeded +12 V (+1.2 g) were also limited to $\leq$ ±10 V (1.0 g) and filtered by 6 Hz, 6-pole Butterworth filters to prevent aliasing, prior to digitization and recording at 20 samples per second. Both the source and the simulator motion tapes were later digitally processed and various statistics of the recorded signals were computed by NSRDC.

Due to unnoticed problems in certain analog-to-digital circuit power supplies, most of the NSRDC recorded data were unusable. Fortunately, NAMRLD had FM-recorded most of the signals of interest in connection with head motion measurements, and these were later digitized and analyzed by NSRDC. In some cases the NAMRLD-recorded signal levels were (inadvertently) too low for adequate digitization, and these have been omitted from this presentation.

The rest of this subsection is devoted to a summary of those statistics, first for the source signals and then for the measured motions. A more detailed comparison of the calculated (source) motions with the actual simulator motions is presented in Subsection III-C.

1. Characteristics of Calculated (Source Tape) Motions

The most important motion statistics are summarized for the originally computed (source tape) conditions in Table III-2. This table lists the standard deviation (σ, the rms about the mean), range (max/min), and characteristic

TABLE III-2. SUMMARY OF SOURCE TAPE (CALCULATED) MOTION STATISTICS FOR GENERIC 2000 TON SES

CONDITION	SEA STATE 3 AT 80 Kt			SEA STATE 4 AT 60 Kt			SEA STATE 5 AT 40 Kt		
NSRDC TAPE NO.	JR 21			JR 19			JR 12		
PARAMETER	σ	Max (Up) / Min (Down)	f_o^+ Hz	σ	Max (Up) / Min (Down)	f_o^+ Hz	σ	Max (Up) / Min (Down)	f_o^+ Hz
Heave Acceleration (g)	0.194	0.662 / −0.554	0.890	0.248	1.05 / −0.676	0.77	0.278	1.38 / −0.710	0.703
Heave Velocity (ft/sec)	1.47	4.03 / −5.19	0.676	2.30	5.47 / −8.80	0.537	3.24	7.26 / −12.77	0.427
Heave Displacement (ft)	0.514	1.36 / −1.62	0.472	1.01	2.58 / −2.97	0.343	2.17	5.85 / −5.91	0.203
Pitch Acceleration (deg/sec^2)	0.949	3.12 / −3.03	1.26	1.61	5.14 / −4.92	0.623	3.83	13.68 / −10.59	0.337
Pitch Rate (deg/sec)	0.286	0.837 / −0.813	—	0.751	1.99 / −1.94	—	2.44	6.11 / −5.44	—
Pitch Angle (deg)	0.180	0.479 / −0.558	0.244	0.523	1.30 / −1.21	0.210	1.87	4.52 / −4.28	0.200
Roll Acceleration (deg/sec^2)	0.278	0.953 / −0.890	2.05	0.651	1.97 / −1.73	0.863	1.32	3.38 / −3.61	0.377
Roll Rate (deg/sec)	0.0600	0.184 / −0.156	—	0.285	0.666 / −0.748	—	0.847	2.12 / −2.31	—
Roll Angle (deg)	0.0207	0.0567 / −0.0589	0.468	0.151	0.317 / −0.409	0.293	0.628	1.34 / −1.47	0.207

Notes:

1. All conditions reflect motion at the center of gravity in a starboard bow sea (ship's heading of 135 deg relative to direction of wave travel).
2. Sigma (σ) and the maximum and minimum values are taken about the calculated mean, whose deviation from zero is an artifact due to math-model mistrim.

frequency* (f_o^+) of: heave acceleration, velocity, and displacement; pitch acceleration, rate, and angle; and roll acceleration, rate, and angle for each of the three source conditions — SS 3/80 kt, SS 4/60 kt, and SS 5/40 kt — as computed from the indicated NSRDC tapes. As noted in the table, all three conditions represent motions at the center of gravity of the SES in a starboard bow sea.

Besides quantifying the increase in the amplitudes of the ship motions with increasing sea state, the source tape data show the following:

- The increasing asymmetry of the heave acceleration and velocity about zero with increasing sea state, wherein upward accelerations exceed downward ones, while downward peak velocities exceed upward ones. These are characteristic of "falling off" the peak of one large wave to the trough of the next one.

- The reduction in characteristic frequency of all variables of motion with increasing sea state.

- The smallness of angular motions relative to heave motions across all conditions.

2. Summary Statistics for Conditions Tested

As discussed previously, all the motion conditions actually run were grouped into eight cells, each defined by one of the three fractions of signal intensity relative to one of the three source conditions. As was shown in Table III-1, each cell groups from 2 to 5 different runs, one of which has been selected to provide the motion statistics representative of each given cell. These typical runs were selected from those relatively few runs for which the taped motion data had been reduced, with the further criteria that: two-pump runs were chosen over one-pump runs, which in no case constituted more than half of the runs within a cell (i.e., for Medium SS 3, Full SS 5), and that a run with the ratio of measured-to-source heave acceleration intensity closest to 1.0 was chosen to represent the "full" condition (Full SS 5), to provide a fair comparison with the source statistics.

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*Characteristic frequency is defined throughout this report as the frequency of positive going zero crossings computed with mean shifted to zero.

A summary of some key heave acceleration statistics for the "typical" runs is provided in Table III-3. This table lists the number of the NAMRLD tape from which the data was derived, the number of the MoGen run on which that tape was recorded, and the following heave acceleration statistics: range (max, min); rms (actually standard deviation) values termed (a) σ, covering the whole spectrum, (b) $\sigma_{<.6}$, covering lower ("kinetosis") frequencies (the ISO-bands from 0.025 to 0.5 Hz, which include the spectrum from 0.022 to 0.56 Hz), and (c) $\sigma_{>.6}$, covering higher ("whole body vibration") frequencies (the 0.63 to 10. Hz ISO bands, which cover the frequency range from 0.56 to 11.31 Hz); f_o^+, the characteristic frequency; and $f_{.5}^+$, the frequency of exceeding +0.5 g. Data are grouped by sea state and, within sea state, are listed in order of increasing total rms G_z. Only 7 of the 8 cell conditions are fully represented, since accurate reduced data were not available for the low SS 4 condition.

As previously noted, reliable comparable statistics are generally not available for the other motion variables of lesser interest, i.e., heave velocity and displacement, and the pitch and roll accelerations, rates, and angular displacements. Table III-4 is a tabulation of the percentage differences of the measured parameter values from their source counterparts for a full (0.89) SS 4 run in July for which good data is available for all motion variables (NSRDC Tape No. HF65). To compare waveform effects, the heave motion maximum, minimum, and rms values were multiplied by the rms heave acceleration attenuation factor (0.89) prior to computing the percentages, i.e., the differences correspond to matched σ waveforms. Table III-4 indicates that source heave velocity and displacement statistics are reasonably representative of the corresponding measured motion statistics though the correspondence is somewhat less precise for peak downward accelerations, upward velocities, and downward displacements. Measured pitch and roll angular displacement statistics also appear to be fairly well represented

TABLE III-3

SOME HEAVE ACCELERATION CHARACTERISTICS OF GROUPED TEST CONDITIONS

CONDITION	NAMRLD TAPE NO.	MOGEN RUN NO.	HEAVE ACCELERATION RANGE Max (Up) (g)	HEAVE ACCELERATION RANGE Min (Down) (g)	RMS G_z OVER WHOLE SPECTRUM σ (g)	RMS G_z OVER 0 - 0.56 Hz RANGE* $\sigma_{<.6}$ (g)	RMS G_z OVER 0.57-10.0 Hz RANGE* $\sigma_{>.6}$ (g)	CHARACTERISTIC FREQUENCY UP ZERO CROSSINGS f_0^+ (Hz)	FREQUENCY OF EXCEEDING +0.5g LEVEL $f_{.5}^+$ (Hz)
Low (2/3) SS 3	SB 116	485	0.465	-0.335	0.126	0.0674	0.107	0.977	0
Medium (4/5) SS 3	SB 134	487*	0.613	-0.413	0.158	0.0853	0.134	0.933	0.0633
Full (1) SS 3	SB 143	489	0.695	-0.495	0.193	0.104	0.163	0.907	0.110
Low (2/3) SS 4	—	—	—	—	~0.17	—	—	—	—
Medium (4/5) SS 4	SB 233	530	0.864	-0.460	0.192	0.108	0.158	0.833	0.117
Full (1) SS 4	SB 236	540	0.978*	-0.579	0.250	0.142	0.206	0.790	0.170
Low (2/3) SS 5	SB 235	538	0.857	-0.431	0.191	0.121	0.148	0.730	0.103
Full (1) SS 5	SB 237	543	1.013*	-0.634	0.282	0.178	0.219	0.700	0.183

Notes:

- Sigma (σ) and the maximum and minimum values are taken about the computed mean, whose deviation from zero is an artifact due to transducer bias.
- All values are measured; they do not presume Gaussian distributions.
- $\sigma_{<.6}$ includes ISO bands from 0.025 to 0.5o Hz (0.56 Hz upper edge); $\sigma_{>.6}$ includes ISO bands from 0.63 to 10.0 HZ (0.56+ Hz lower edge).
- $\sigma = (\sigma^2_{<.6} + \sigma^2_{>.6})^{1/2}$.

*Data recorded during first three hours of run prior to MoGen recalibration.

TABLE III-4

PERCENTAGE DIFFERENCES OF MEASURED FROM SOURCE PARAMETER VALUES
FOR FULL SEA STATE 4*

PARAMETER	HEAVE VARIABLES			PITCH VARIABLES			ROLL VARIABLES		
	$\ddot{h}$	$\dot{h}$	h	$\ddot{\theta}$	$\dot{\theta}$	θ	$\ddot{\varphi}$	$\dot{\varphi}$	φ
σ	0 (ref)†	+1.5	−1.8	+106	+5.6	−17	+179	−3.2	−21
Max / Min (Up)/(Down)	+2.6‡/−15	+11/−2.4	−.4/+17	+330/+117	+8.5/+33	−17/−12	+524/+463	+107/+5.7	+13/−27
f_o^+	−1.8	+4.3	+5.8	+217	NA	+11	+172	NA	0

*Source tape was JR 19, measured data from Tape HF-65.

†Defined as zero in order to scale the source to the measured condition.

‡May not be accurate because measured value equalled +1 g limit imposed by measurement filter.

NA = source data not available.

by their source counterparts, but the large differences indicated for negative measured pitch rate and positive measured roll rate, and the even larger increments in all the measured angular acceleration statistics, testify to the presence of the high frequency structural modes mentioned earlier in Section II. While these modes do not appreciably affect angular displacement, which is a good indicator of relative motion effect, they do change the rms angular rates and accelerations. Nevertheless, these small vibratory motions were not apparent or annoying to the crew in Phase II, and the match of angular motions is considered satisfactory.

Figure III-1 summarizes graphically some of the heave acceleration characteristics of the measured motion from Table III-3 and compares them with those of the calculated motion. The top figure shows the range and rms intensity of heave acceleration. As previously noted, the MoGen gain calibration was eventually accomplished by matching source and measured rms intensity from an on-line measurement,* and the measured signals for the Full (1.0) SS 3, SS 4, and SS 5 conditions verify this adjustment. The positive and negative peak data show that the MoGen tends to increase the existing skew of the calculated data range in the direction of upward accelerations, but the change in peak acceleration values is not large enough to compromise the essential character of the 2000 Ton SES motions. As is also evident from this figure, the asymmetry for full measured motion is preserved across intensity levels for a given sea state.

Figure III-1b is a plot of rms intensity versus characteristic frequency. (Note the displaced origin in the abscissa scale which tends to exaggerate differences in characteristic frequency.) Actual differences within sea state were small, with characteristic frequencies for full measured conditions closely matching those for corresponding Source conditions. Characteristic frequency is shown to increase with decreasing acceleration intensity, but remains within 8 percent of that for full intensity. Further, it does not overlap on the range of values for the neighboring lower sea state. Overall,

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*These on-line measurements were obtained by substituting the command and measured acceleration signals for the error and control signals in the Dual-Axis Tracking Task as mechanized on the HFR REDCOR computer.

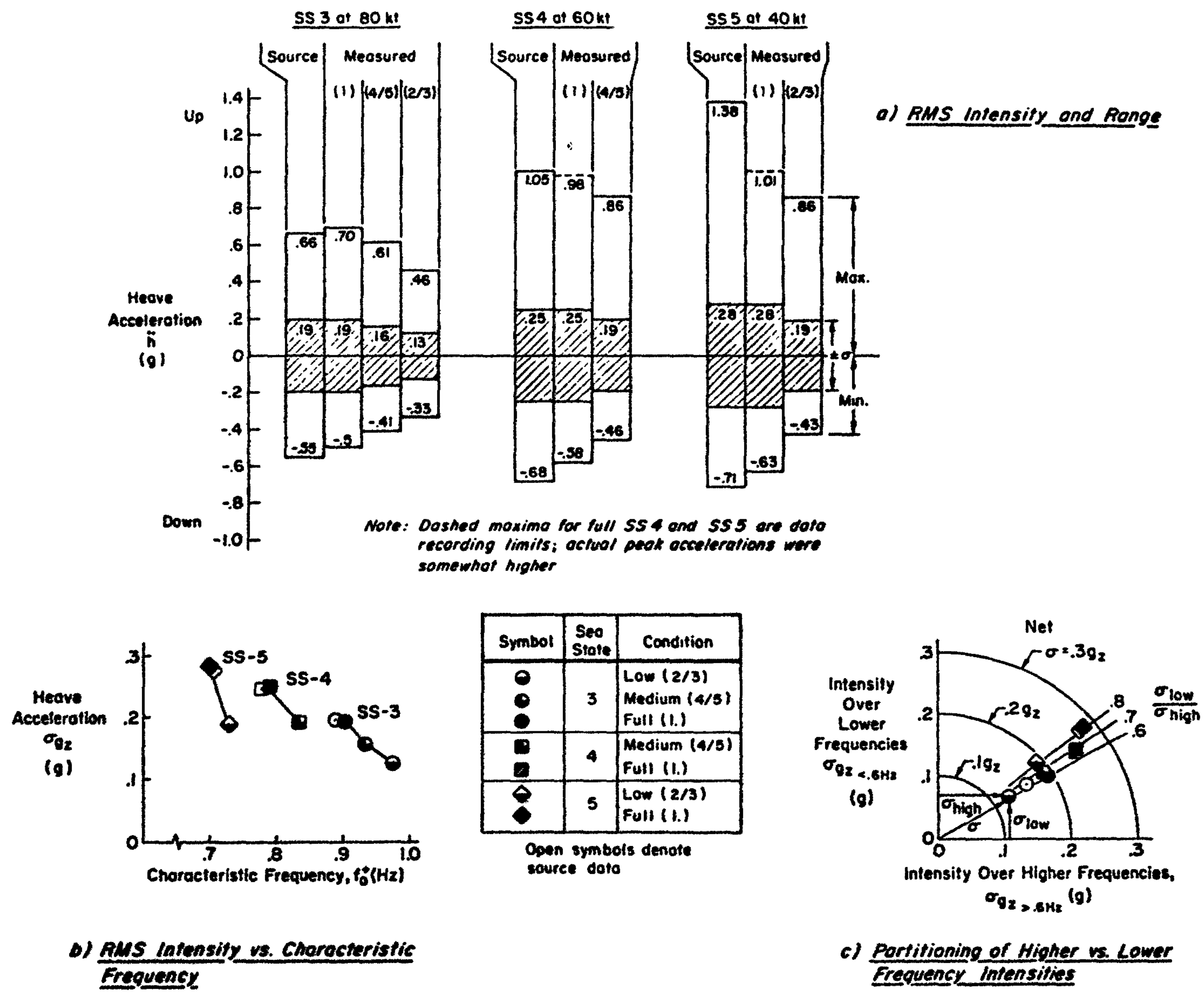


Figure III-1. Summary of Phase II Motion Properties

characteristic frequencies for all the measured motion conditions extend nearly uniformly from 0.70 to 0.98 Hz as condition varies from Full SS 5 to Low SS 3.

The third figure of the set, Figure III-1c, shows the division of intensity over the lower (kinetosis) and the higher (whole body) frequency ranges, as previously defined. On this plot a constant total rms acceleration, which is the root-sum-square of the two components, lies on circles about the origin. Here again Source data are closely matched by that for the Full measured conditions. The fact that the ratio of low-frequency to high-frequency intensity remains constant for a given sea state for varying total intensity levels further attests to the fidelity with which the MoGen reproduced these generic 2000 Ton SES motions.

Before leaving Fig. III-1, one more comparison is in order, namely, that across the three different sea state conditions for which the rms intensities were adjusted to be equal to 0.19 g: Full (1.0) SS 3 (●), Medium (4/5) SS 4 (▩), and Low (2/3) SS 5 (◈). Consideration of these three conditions in Fig. III-1 indicates that

- The rms amplitude do match as intended.
- The amplitude peak characteristics of Medium SS 4 are closer to those of Low SS 5 than to those of SS 3.
- The characteristic frequencies progress downward in roughly equal increments from SS 3 to SS 5A.
- The proportion of "kinetosis" to "whole body" motion progresses from roughly $\sigma_{<.6}/\sigma_{>.6}$ = 0.6+ to 0.7 to 0.8 in going from SS 3 to 4A to 5A.

Thus this set of conditions appears to meet the desired objective of simulating equal intensity motions, which are distinct in waveform from one another.

The presentation of more detailed heave acceleration properties for each typical condition is provided in the following subsection.

C. DETAILED MOTION PROPERTIES

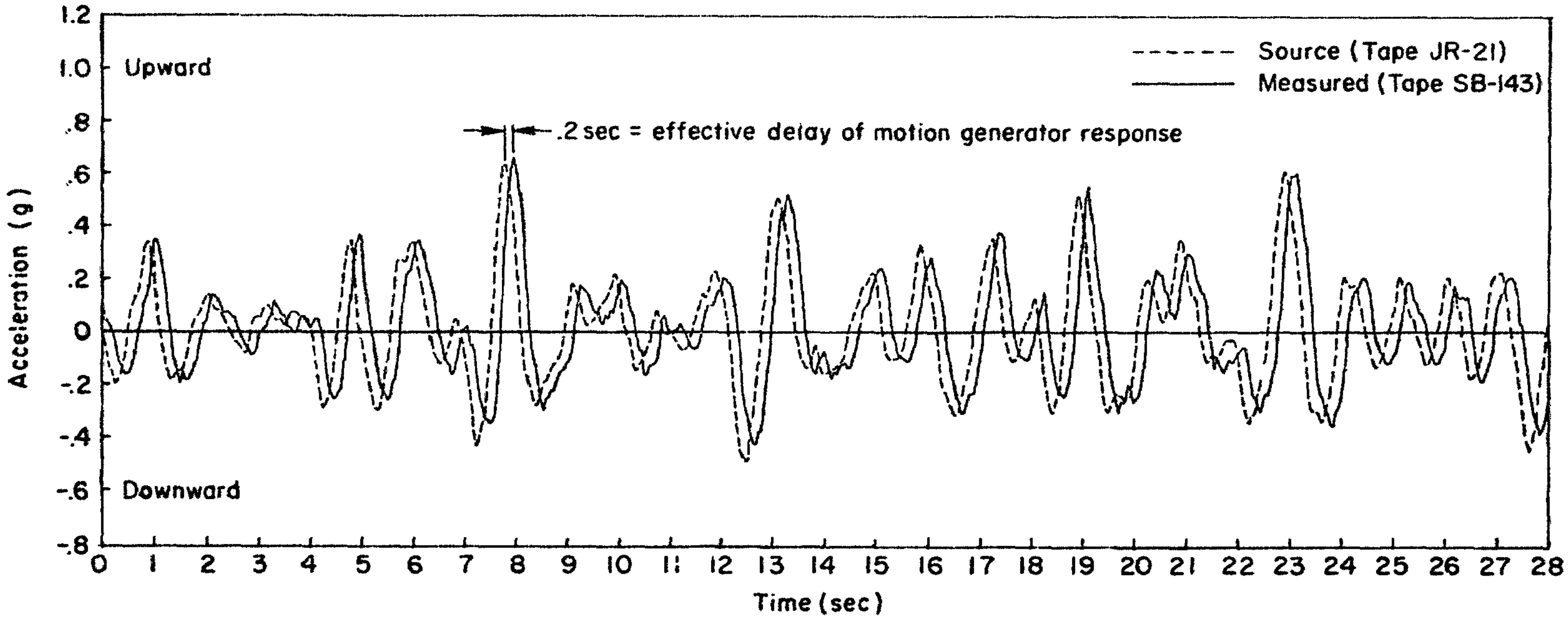
In this subsection the detailed properties of both source and measured heave acceleration waveforms, summarized in the previous subsection, are presented for each of the three sea state conditions, beginning with a comparison of time histories for source and measured motions followed by their amplitude characteristics and frequency characteristics.

1. Properties of Starboard Bow Sea State 3 at 80 kt

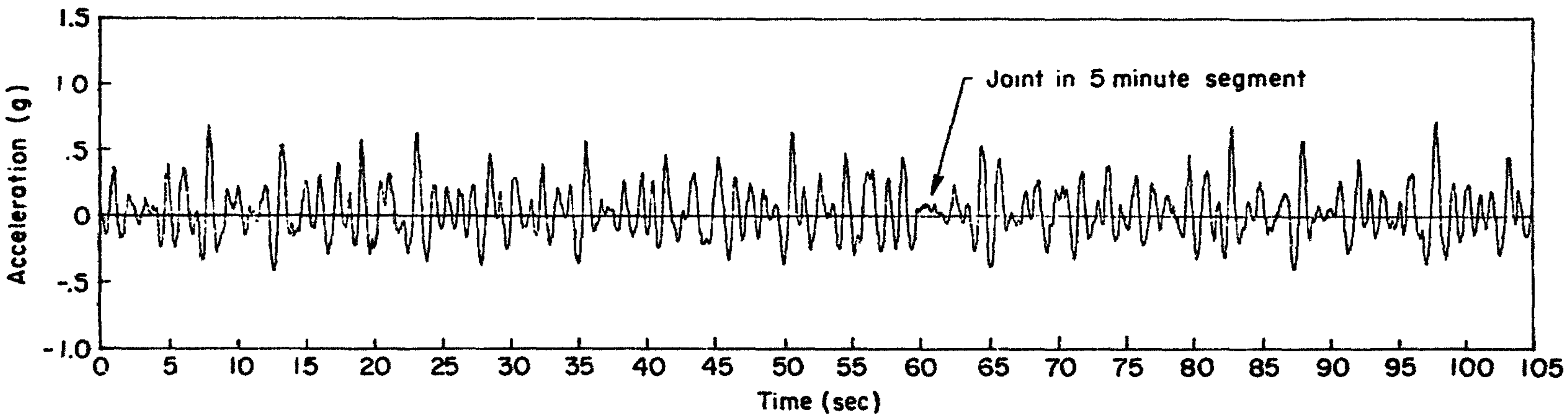
Time histories of the full intensity SS 3 heave acceleration waveform are shown in Fig. III-2. These time traces were computer generated by APL/JHU using a routine that connected with straight lines the 20 per second digital points from the NSRDC source (Tape JR-21) and measured motion (SB 143). The top trace compares the source and the measured motions on an expanded time scale and elicits the following observations:

- The commanded waveform is not shown, because it is almost identical to the source signal, except for being clipped at +1.0 g (for certain sea states).
- The measured acceleration closely follows the source waveform, although lagging it by about 0.2 sec. This MoGen response lag closely approximates a pure delay, most of which was intentionally introduced to match existing delays in the pitch and roll drive systems (see Section II-A). Thus motion in the three-degrees-of-freedom is synchronized, and the character of the simulated motion is preserved.
- The previously noted (in Section II) nonlinear tendency of the MoGen to slightly undershoot low amplitudes and overshoot high amplitues is barely perceptible in the actual signals.
- The ragged nature of the measured signal near most peaks is due both to slight MoGen deadband and friction effects and to artifacts of data sampling and reconstruction.

The bottom of Fig. III-2 shows a typical portion of the measured heave acceleration time history for the Full SS 3 condition, with the time scale compressed to allow observation of about 100 seconds of waveform character. Notice the following points:



a) Comparison of Source and Measured Waveforms



b) Typical Measured Waveform

Figure III-2. Heave Acceleration Time Histories for Source and Full Measured Starboard Bow Sea State 3/ 80 kt Conditions

- The waveform appears to be uniformly random, and it does not exhibit periodic patterns, patchiness, or "signature-like" pulses which might enable crewmen to detect the 5 minute repeat period.

- While, at first glance, the waveform appears fairly symmetric, close examination shows that acceleration waveform (and velocity waveform — not shown) are not symmetrically disposed; the peak positive acceleration levels tend to be somewhat greater than peak negative levels.

These peaks in acceleration show the classic asymmetry associated with riding up to crest a wave and dropping off into the trough. The resulting traces are characterized by acceleration spikes of low negative magnitudes when the ship drops off the crest and noticeably higher positive magnitudes as the bow hits a trough. These properties are discussed and more completely illustrated in the Phases I and IA report (Ref. 6). These asymmetries are accentuated at the higher sea states.

Heave acceleration amplitude probability densities (histograms) for the source and the typical measured SS 3 conditions are presented in Fig. III-3. These, and the amplitude density plots for the other sea state conditions whose description follows, are plotted to common vertical and horizontal scales with areas normalized to the same value, making direct comparison possible. Each density plot is accompanied by a (dotted G) Gaussian density function having the same mean, sigma, and area as actual data, further facilitating plot comparison. Integral multiples of sigma are marked off on a separate abscissa scale below the horizontal axis label. The slight shift in the mean, shown on some of these plots, is an artifact of the accelerometer's thermal drift. Sigmas for the Source and Full measured SS 3 conditions are almost identical so the Gaussian densities provide a common reference against which to judge differences between the two densities. Examination shows the two densities to be very similar, both being nearly Gaussian with both positive and negative tails (beyond $\pm 2\sigma$) shifted to more positive (leftward) values of acceleration mean. This shifting of the tails corroborates the asymmetries observed in the time traces, and careful examination of the two top plots reveals the further reduction in negative peak levels introduced by the

"Dotted-G" curves are Gaussian distributions
with the actual distribution mean and sigma

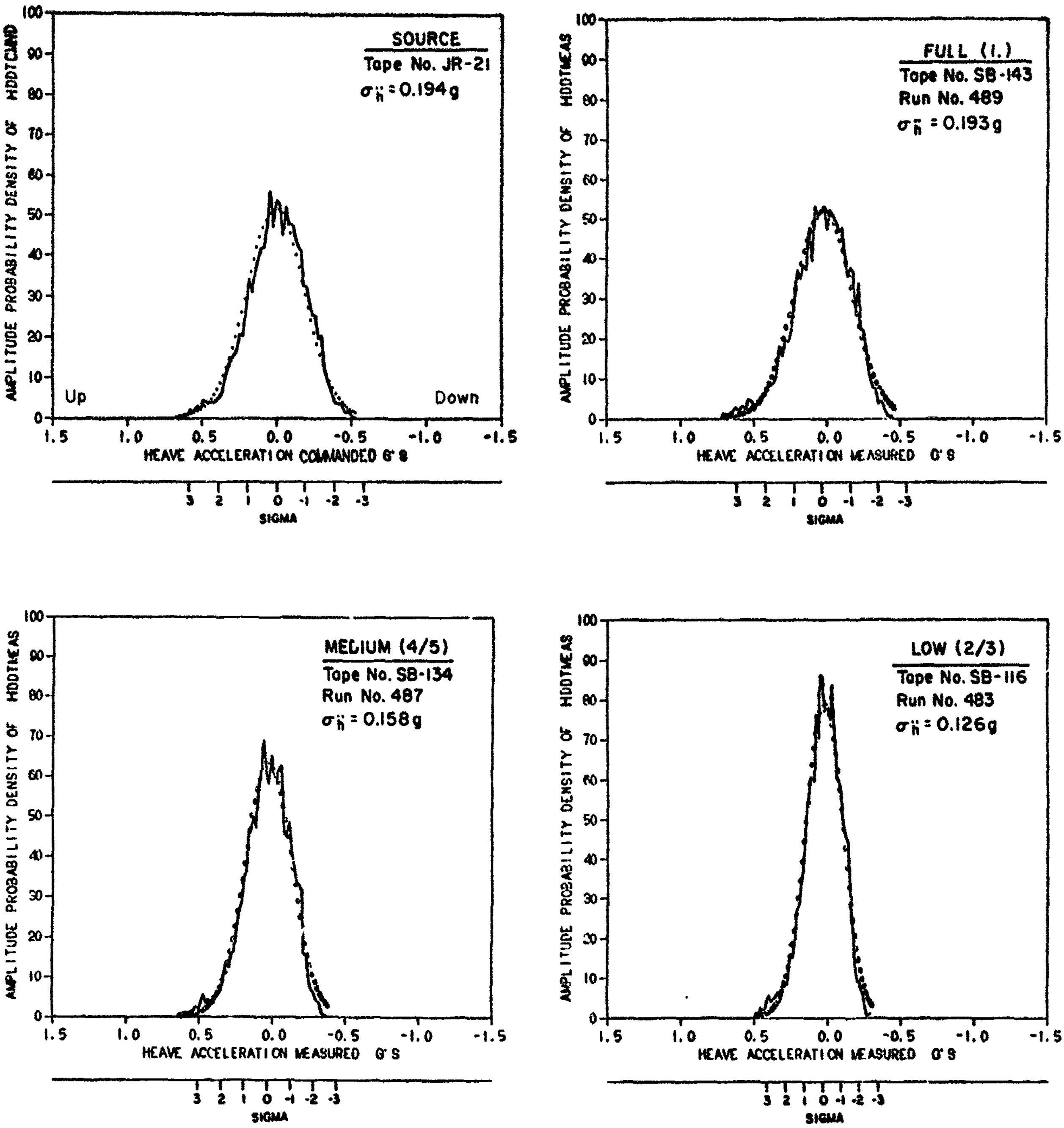


Figure III-3. Amplitude Probability Densities for Source and Typical Measured Starboard Bow Sea State 3/80 kt Conditions

MoGen. The heave acceleration densities for the Medium and Low SS 3 conditions show the same essential character as that for the Full SS 3 condition over their reduced acceleration range, indicating that this property is preserved by the attenuation process.

Figure III-4 provides further details on the amplitude characteristics of the same SS 3 conditions. The top plot presents acceleration-exceedence-frequency data for the Source and the typical measured motions. The curves are very similar to the probability density plots just presented (they would be exactly proportional if the waveform were narrowband Gaussian-with roughly constant slope segments between zero crossings). The close approximation of the exceedence-frequency curves to the amplitude distribution has some useful implications with respect to the calculation of the probabilities of severe motions, loads, or of slamming, but that is a topic for another report. In addition, they show another result of MoGen non-linearities: a slight increase in characteristic frequency ("exceedence frequency" of 0.0 acceleration) with reduction in intensity level as discussed in the previous subsection.

Using the inverse-frequency scale given on the right hand of the exceedence plot, average-time-between-level crossings can be read off. For example, the Full SS 3 waveform exceeds +0.5 g upward about every 10 sec, <u>on the average</u> while that of Low SS 3 (almost) never exceeds 0.5 g. Fig. III-4b shows the time density histogram for which the zero crossing interval of 1.1 sec is the mean. A Gaussian density, having the same mean and sigma and shown by the dashed line, fits the histogram fairly well, except in the tails (again, perfectly Gaussian narrowband signals would yield a Gaussian interval histogram, see Ref. 10). The corresponding histogram for the source condition is very similar to that presented. Histograms for the time between exceedences of high g levels were not generated, because the available data were too sparse, but on the basis of these waveforms and histograms we would expect a random distribution of intervals between exceedences.

Power spectral densities (PSD) for the SS 3 ensemble are presented in Fig. III-5. The "peaky" nature of the PSD is a consequence of the seaway model used as an input to the 2000 Ton generic SES representation,

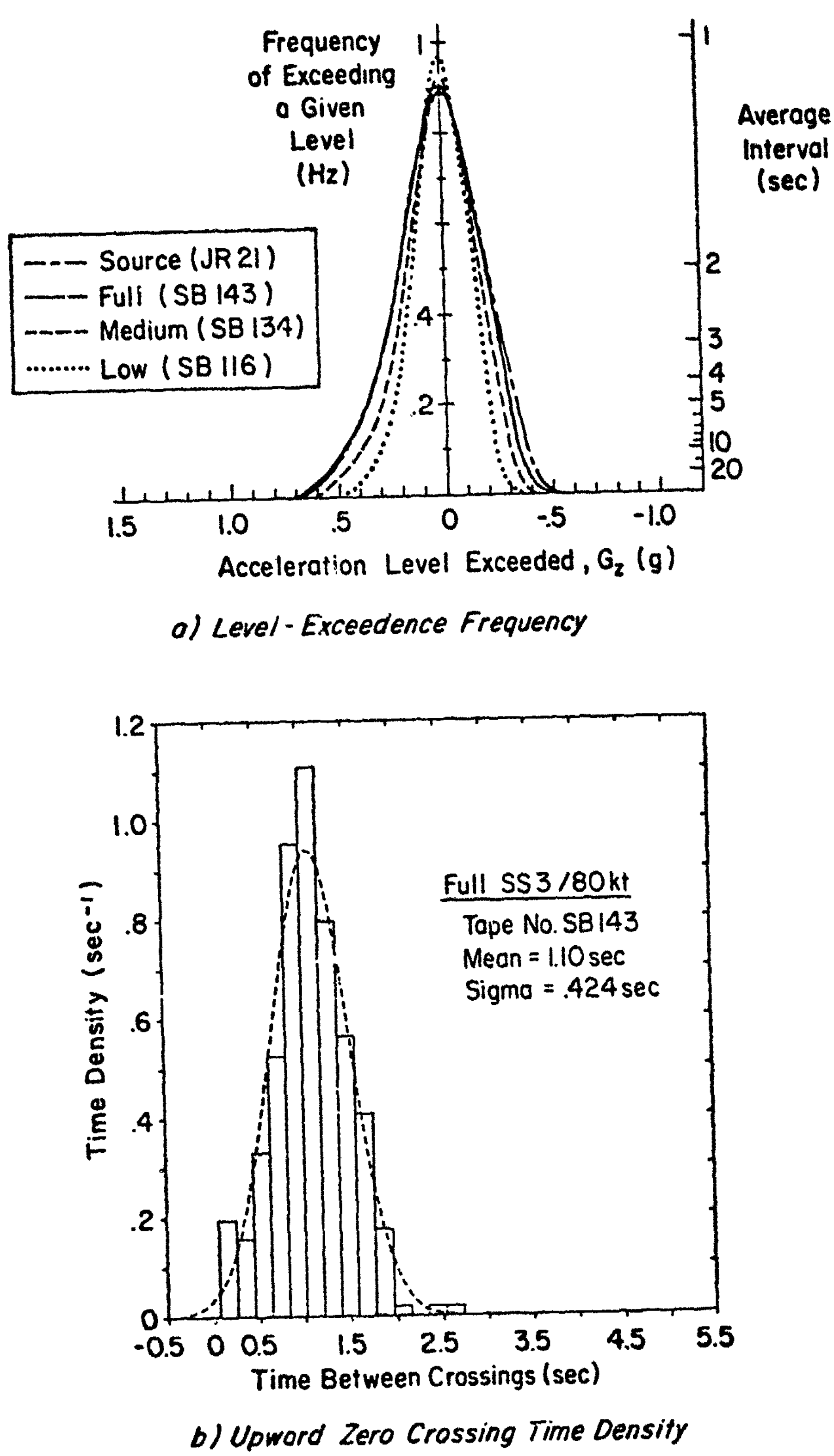


Figure III-4. Level Crossing Statistics for Source and Typical Measured Starboard Bow Sea State 3/80 kt Conditions

(Value in parentheses is rounded fraction)

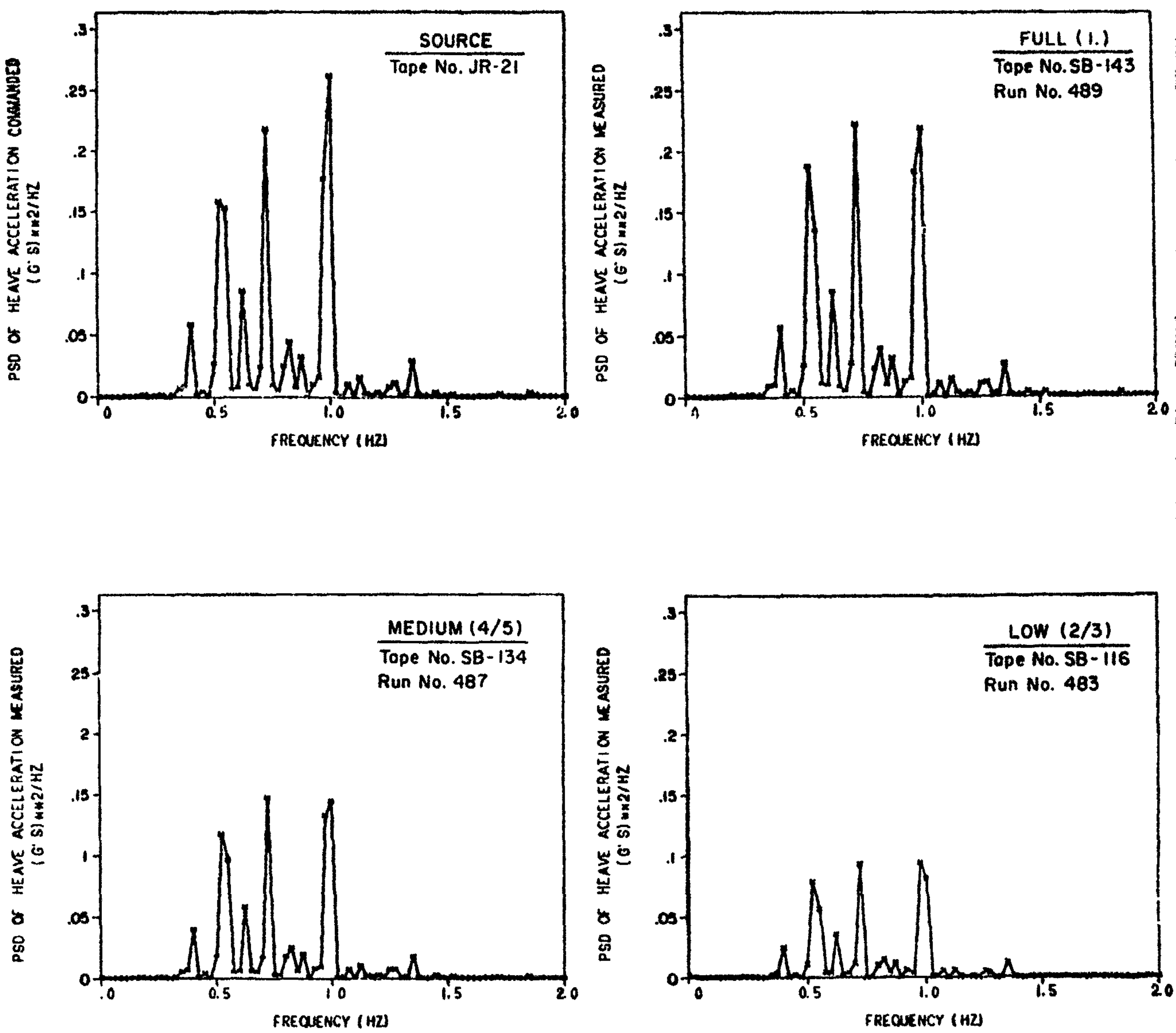


Figure III-5. Power Spectral Densities for Source and Typical Measured Starboard Bow Sea State 3/80 kt Conditions

which consists of a sum-of-sinusoids appropriately distributed over the actual seaway spectrum (Ref. 9). All source peaks are clearly reflected in the MoGen output for each of the three measured conditions, but changes in wave encounter frequency due to ship speed fluctuations, the small bandwidth (0.025 Hz) of the PSD, and distortion introduced by noninteger number of cycle run lengths and the sampling process, and MoGen nonlinearities, smears the spectral lines into peaks and alters the relative height of peaks delineated by more than one data point.

The third octave bands of the ISO-type spectra, which shows the rms g in each 1/3 octave band (which nearly equals a 1/10 decade band) on log-log scales, are presented in Fig. III-6; these provide a smoother comparison of the amplitude frequency characteristics of source and measured conditions over the frequency range of interest. Note that these spectra and those to follow are not shown beyond 5 Hz, because the 6 Hz, 6-pole Butterworth anti-aliasing filters attenuate both the recorded command and measured signals. Note, in general, that differences from the source spectrum at amplitude levels below 0.01 g rms — which are blown out of proportion by the logarithmic scaling of acceleration intensity — have no practical importance. The source spectrum is shown only where visibly different from Full measured.

Comparing then, the amplitude-frequency characteristics above this level, we see the Full measured SS 3 acceleration spectrum follows the source very closely, the most notable differences between the two coming at levels less than 0.02 g rms at higher frequences, reflecting the slight roughness noted in the time traces. The character of the attenuated (Medium and Low) spectra is accurately preserved at all frequencies, as attested by their constant displacement on the log scale. Note also that 99% of the power is contained within the ISO bands with center frequencies from 0.5 to 1.25 Hz (i.e., from 0.35 to 1.41 Hz edge-to-edge).

2. Properties of Starboard Bow Sea State 4 at 60 kt

Time histories of the Full intensity SS 4 heave acceleration waveform are shown in Fig. III-7. This matched set of Source and Full measured traces on the top generally shows the same characteristics noted earlier

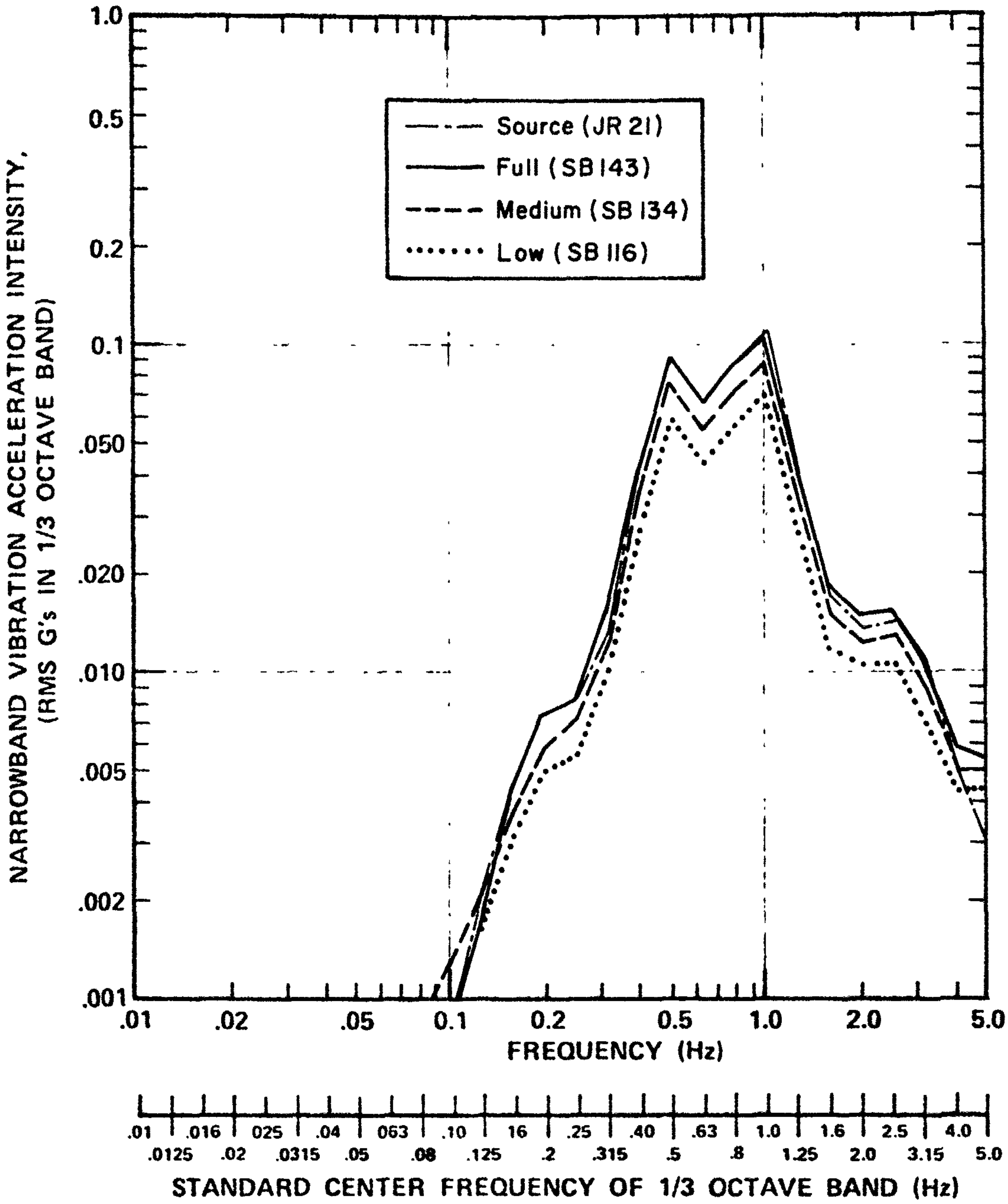
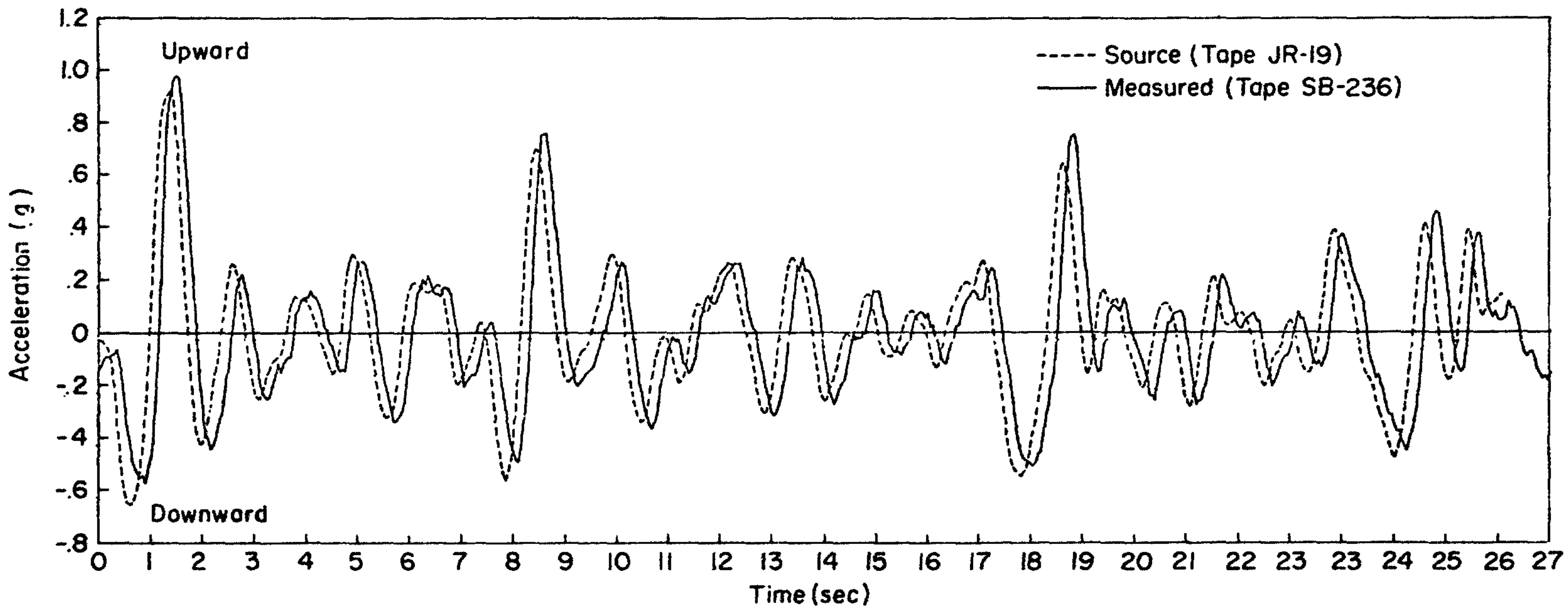
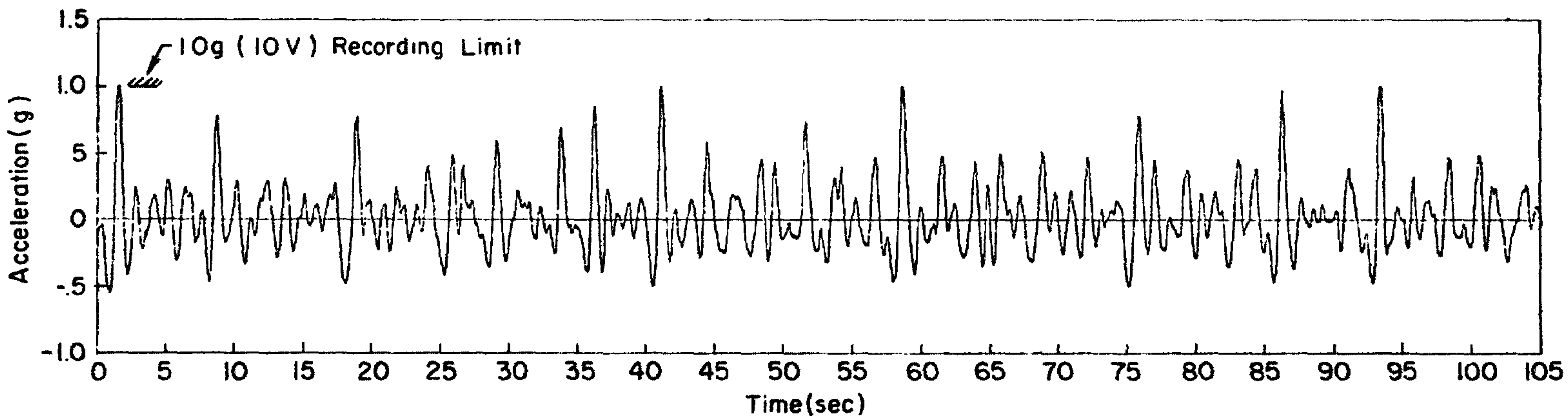


Figure III-6. Comparison of ISO Spectra for Source and Typical Measured Starboard Bow Sea State 3/80 kt Conditions



a) Comparison of Source and Measured Waveforms



b) Typical Measured Waveform

Figure III-7. Heave Acceleration Time Histories for Source and Full Measured Starboard Bow Sea State 4/ 60 kt Conditions

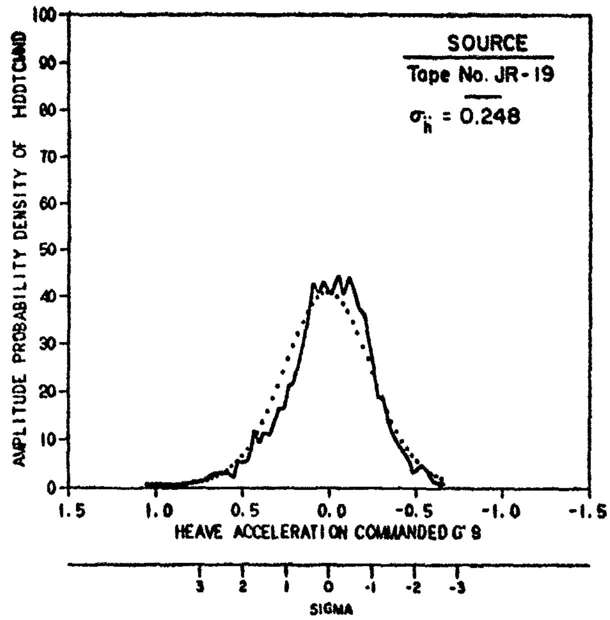
for the SS 3 comparison: measured acceleration follows 0.2 sec after the source and recreates it very accurately. The traces show the same source asymmetries due to wave hopping noted earlier, though these are more pronounced for this rougher sea state. Examination of Fig. III-7b shows that there is also slightly less uniform stationarity in the generated SS 4 waveforms than in SS 3, with less regularity in the interpeak interval and more patchiness over time, the latter related to the increased bandwidth of the signal which shows in the ISO spectrum subsequently presented. Not shown on this particular segment is an occasional limiting of the recorded signals when the measured peaks exceeded +1.0 g very briefly.

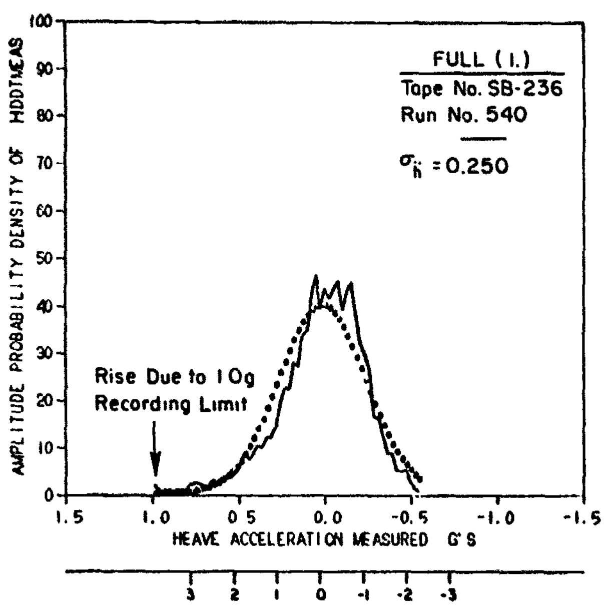
Amplitude distributions are shown in Fig. III-8 for Source and Full and Medium measured SS 4 accelerations. (As already noted, accurate data are not available for Low measured SS 4). As in the SS 3 case, the measured motion histograms are very similar to that for the source signal, showing positively skewed and flat-topped but near-Gaussian distributions. Incidentally, the small hump at the end of the +1.0 g tail of the Full measured curve actually indicates the rare occurrence of MoGen accelerations slightly in excess of 1 g, which were limited at the +10 V (1.0 g) level in the recording process.

The corresponding stacked ensemble of acceleration-level exceedence frequency plots is shown in Fig. III-9. Comparison of the Fig. III-9a curves for Source and Full measured SS 4 shows the same characteristic MoGen-induced accentuation of waveform skewness as for the SS 3 plots. As before, the source waveform amplitude properties are faithfully preserved at both levels of measured intensity, except for the slight increase in characteristic frequency with decreased intensity. Peaks exceeding +0.5 g occur, on the average, every 7 sec for Full SS 4 and every 12 sec for Medium SS 4. Figure III-9b shows the upward zero-crossing interval density which gives a mean interval of 1.26 sec for the Full measured SS 4 waveform, corresponding to $f_0^+ = 0.79$ Hz, above. The histogram shows a skew toward longer intervals not apparent in its SS 3 counterpart.

Figure III-10 presents the power spectral densities for the source and typical measured SS 4 conditions, the latter clearly matching the former.

"Dotted-G" curves are Gaussian distributions with the actual distribution mean and sigma





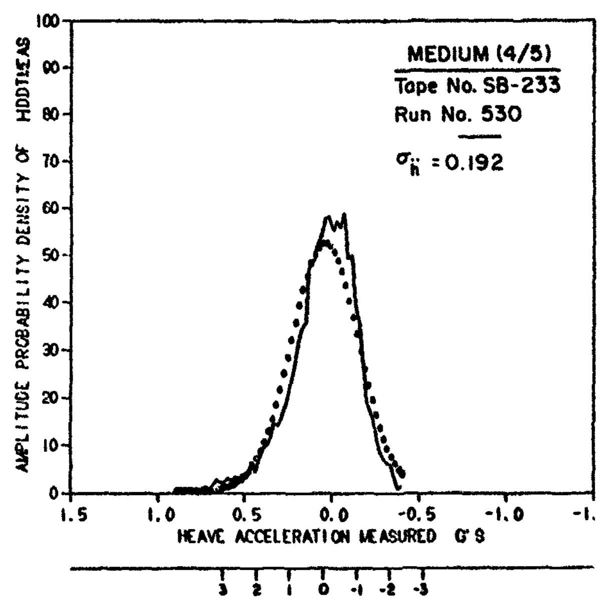


Figure III-8. Amplitude Probability Densities for Source and Typical Measured Starboard Bow Sea State 4/60 kt Conditions

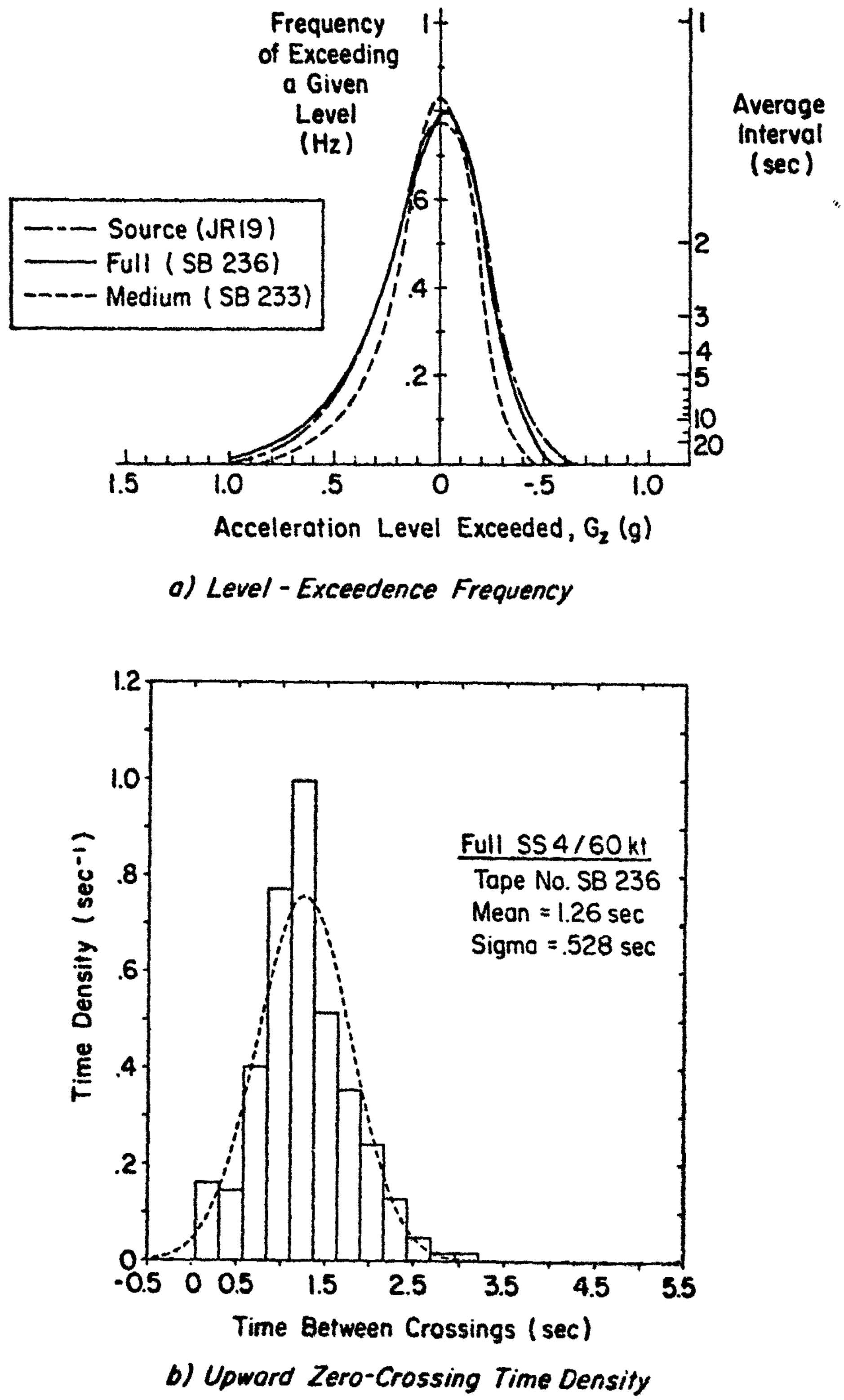


Figure III-9. Level Crossing Statistics for Source and Typical Measured Starboard Bow Sea State 4/60 kt Conditions

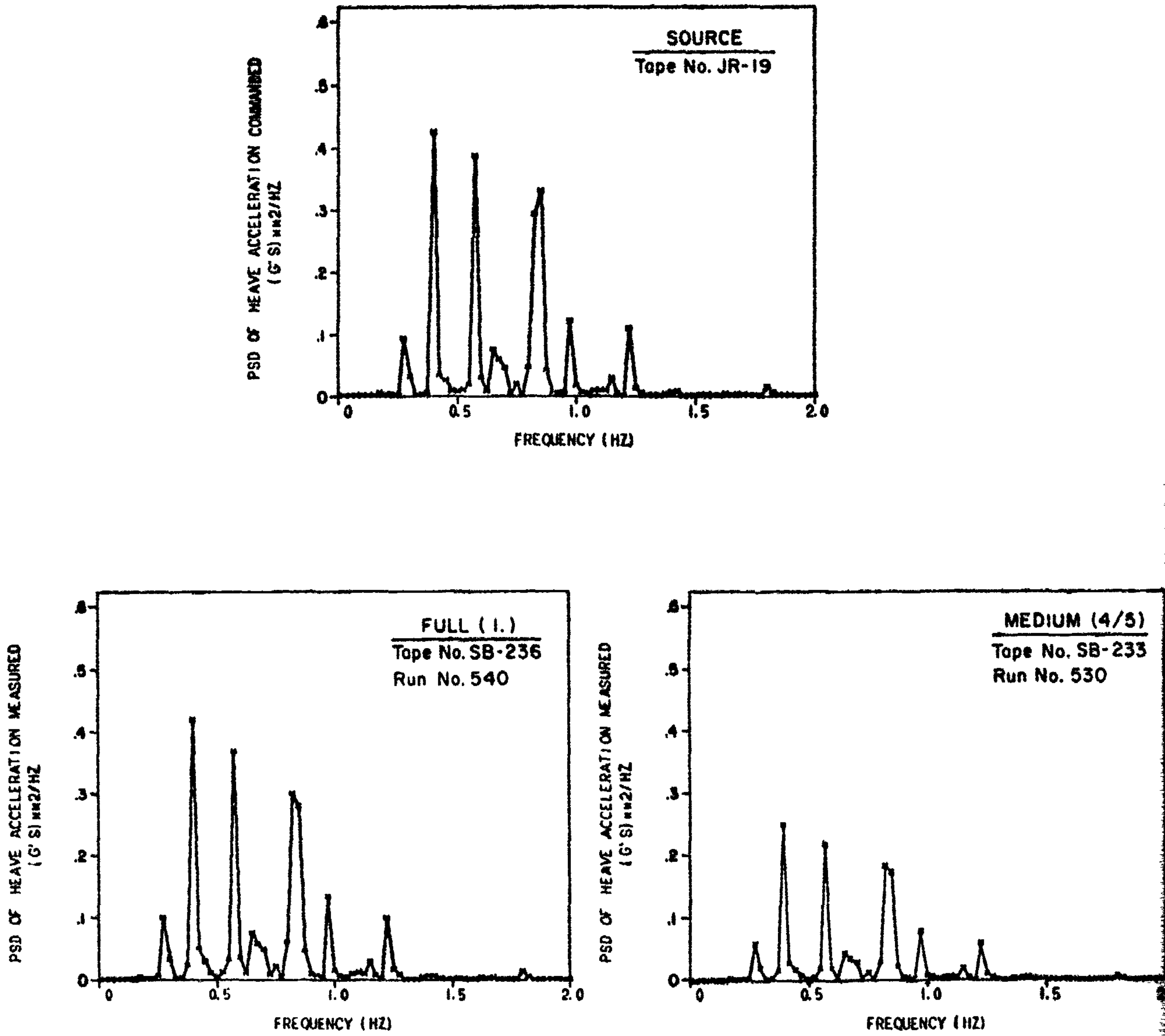


Figure III-10. Power Spectral Densities for Source and Typical Measured Starboard Bow Sea State 4/60 kt Conditions

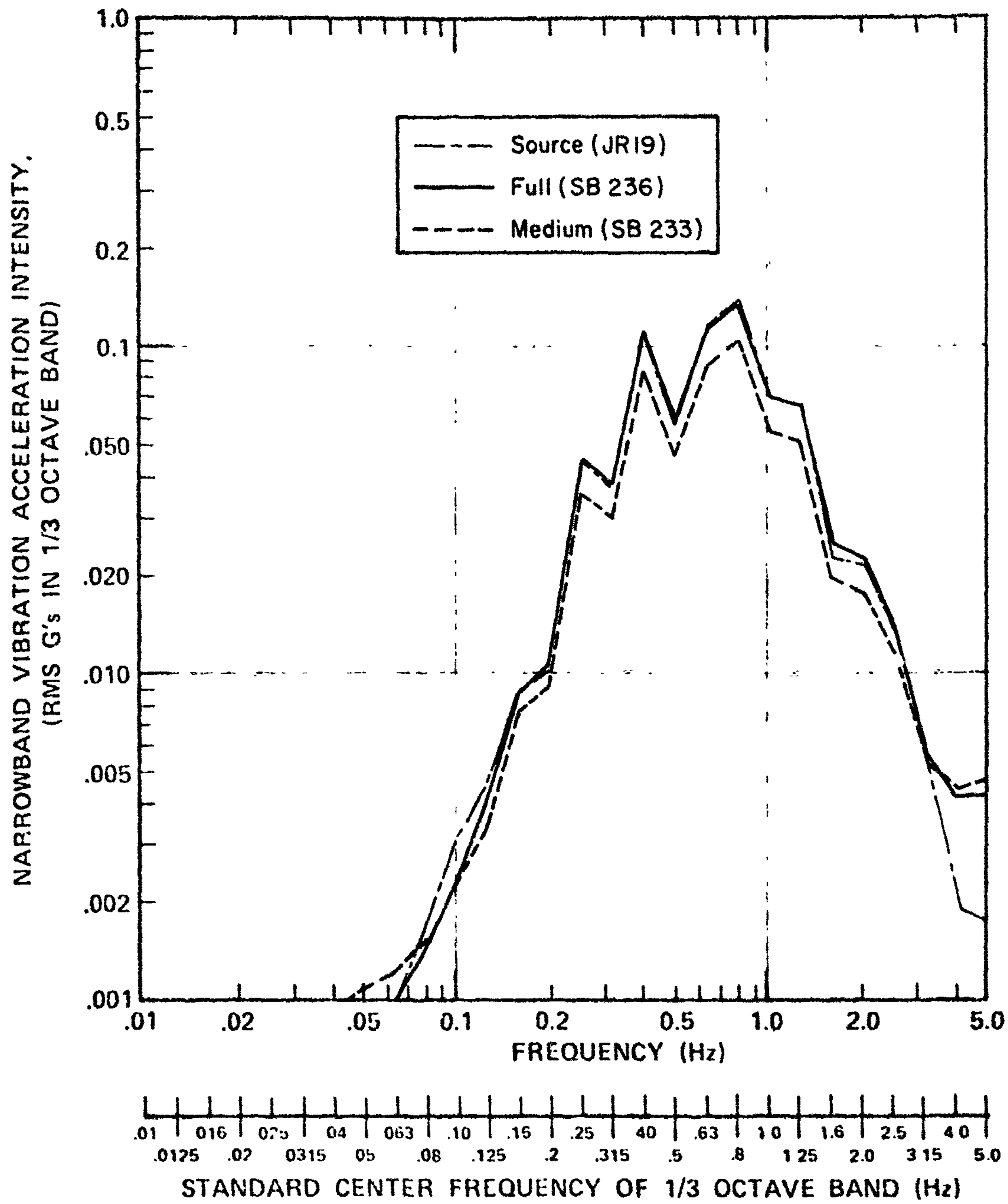


Figure III-11. Comparison of ISO Spectra for Source and Typical Measured Starboard Bow Sea State 4/60 kt Conditions

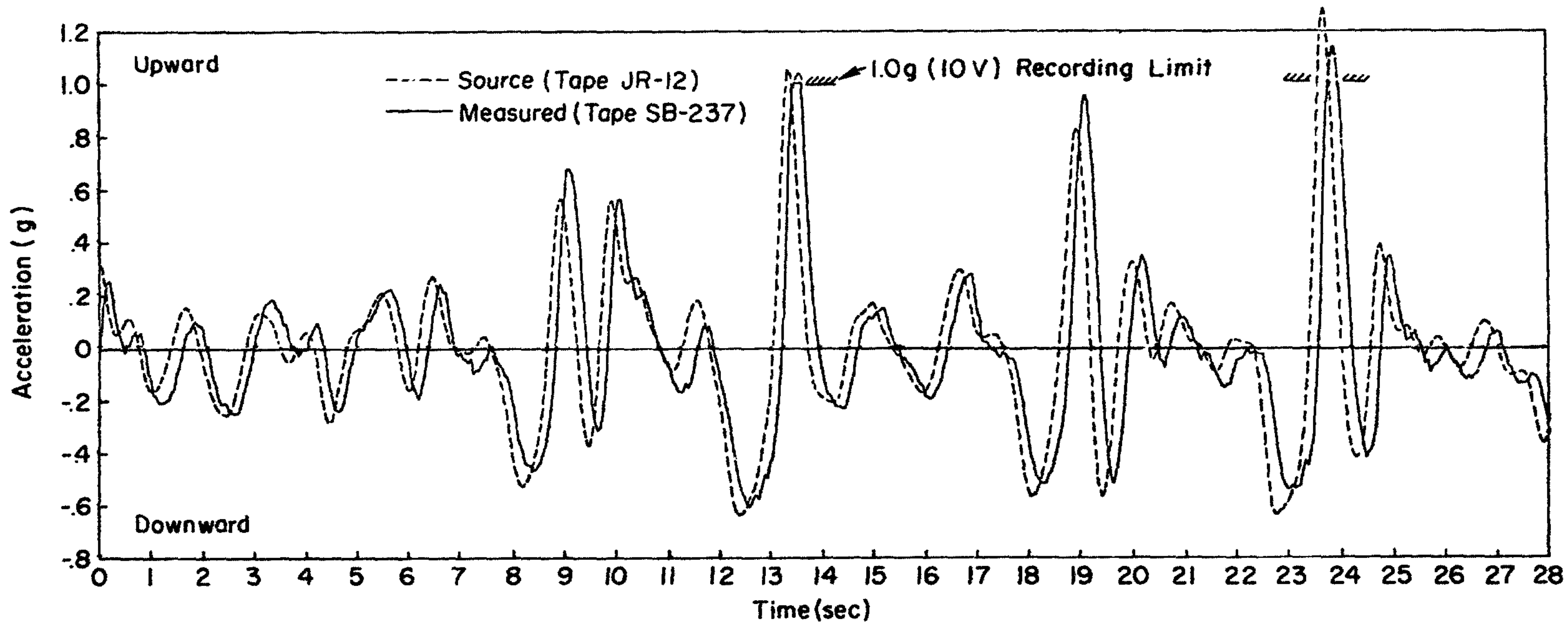
Corresponding ISO spectra are given in Fig. III-11. As was true for the SS 3 condition, they demonstrate the preservation of the intensity distributions with frequency over the range of significant amplitudes, i.e., above 0.01 g rms. They also show an effective bandwidth over ISO center frequencies from 0.25 to 1.25 Hz (i.e., from 0.22 Hz to 1.41 Hz).

3. Properties of Starboard Bow Sea State 5 at 40 kt

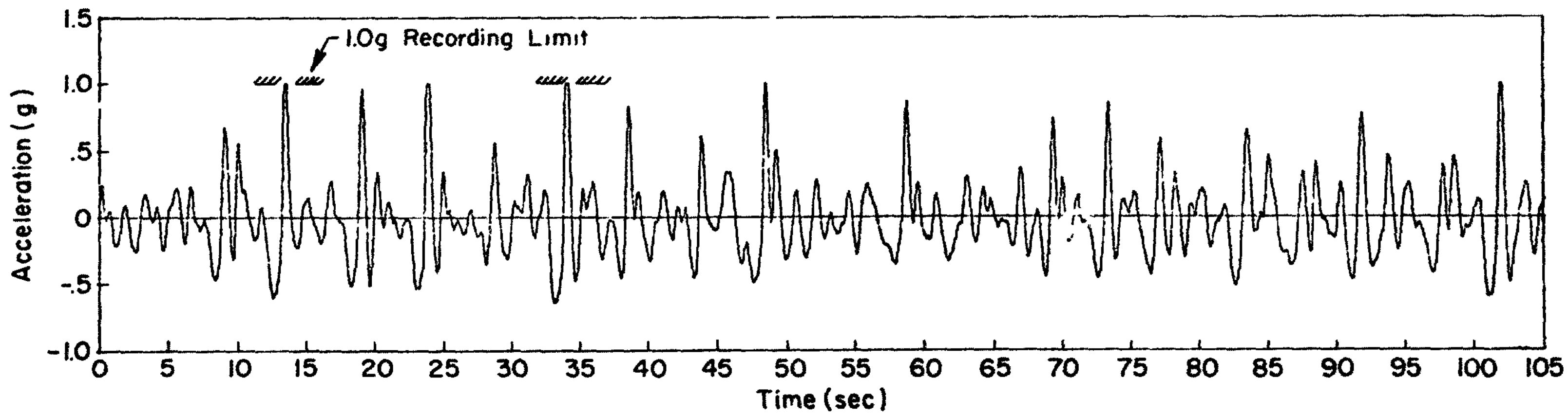
Time histories of the Source and Full measured SS 5 acceleration waveforms are shown in Fig. III-12. Comparison of the traces in the top figure once again indicates the high fidelity with which the upgraded MoGen reproduced the calculated 2000 Ton generic SES motions. The measured peaks are truncated at 1 g on the taped recording, but the actual simulator acceleration reached peaks on the order of 1.1 g. The bottom trace of Full measured acceleration shows a randomness and lack of regularity which surpasses that of the SS 3 and SS 4 motions, with more pronounced lulls in wave activity and greater variability in recurrent time of the large peaks. The increased frequency of peaks exceeding ±0.5 g, compared to previous conditions, is readily apparent.

Figure III-13 presents the amplitude distributions for the source and Full and Low measured SS 5 heave accelerations. Once again the measured distributions mirror that of the source, all showing a leptokurtic (narrow, pointed) character with an extended positive tail and a sharply truncated negative tail which is not fit by the Gaussian representation. (Note, however, that within $\pm 2\sigma$ all the curves would be fairly well represented by a Gaussian curve of lower sigma and slightly shifted mean). The Full SS 5 density shows the effects of the 1.0 g recording limit which lumps all time spent at greater g levels at that limit. This spike should be rotated 90 deg counterclockwise to reflect the true distribution.

Level crossing statistics for the SS 5 ensemble are given in Fig. III-14. Note the lesser variation in characteristic frequency from Full to Low intensity SS 5 compared with those for SS 3 and SS 4, accompanied by an increase in the spread and positive skewness of the upward zero-crossing time density. The average interval between +0.5 g exceedences is about 6 sec for Full SS 5 and 10 sec for Low SS 5.



a) Comparison of Source and Measured Waveforms



b) Typical Measured Waveforms

Figure III-12. Heave Acceleration Time Histories for Source and Full Measured Starboard Bow Sea State 5/ 40 kt Conditions

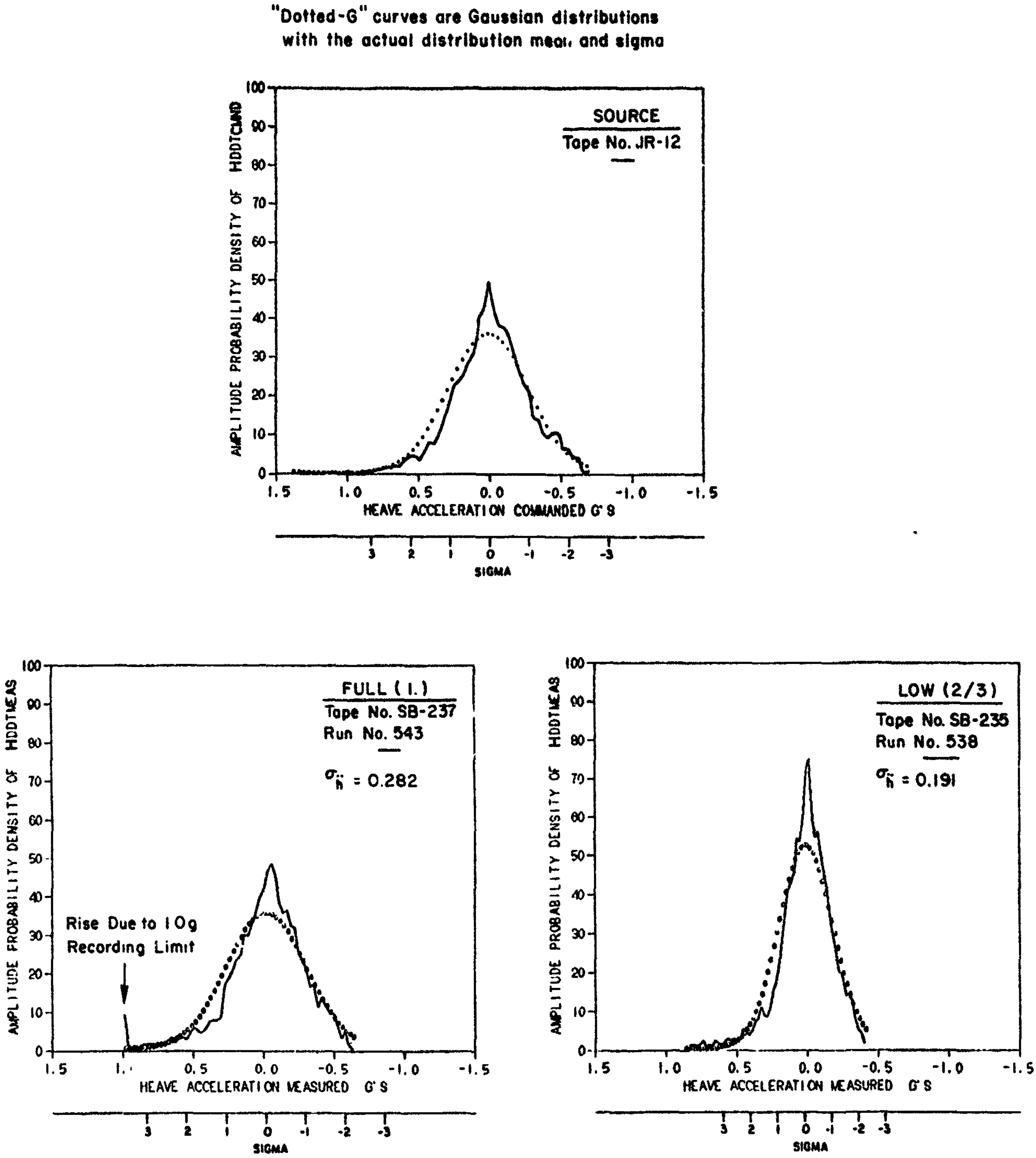
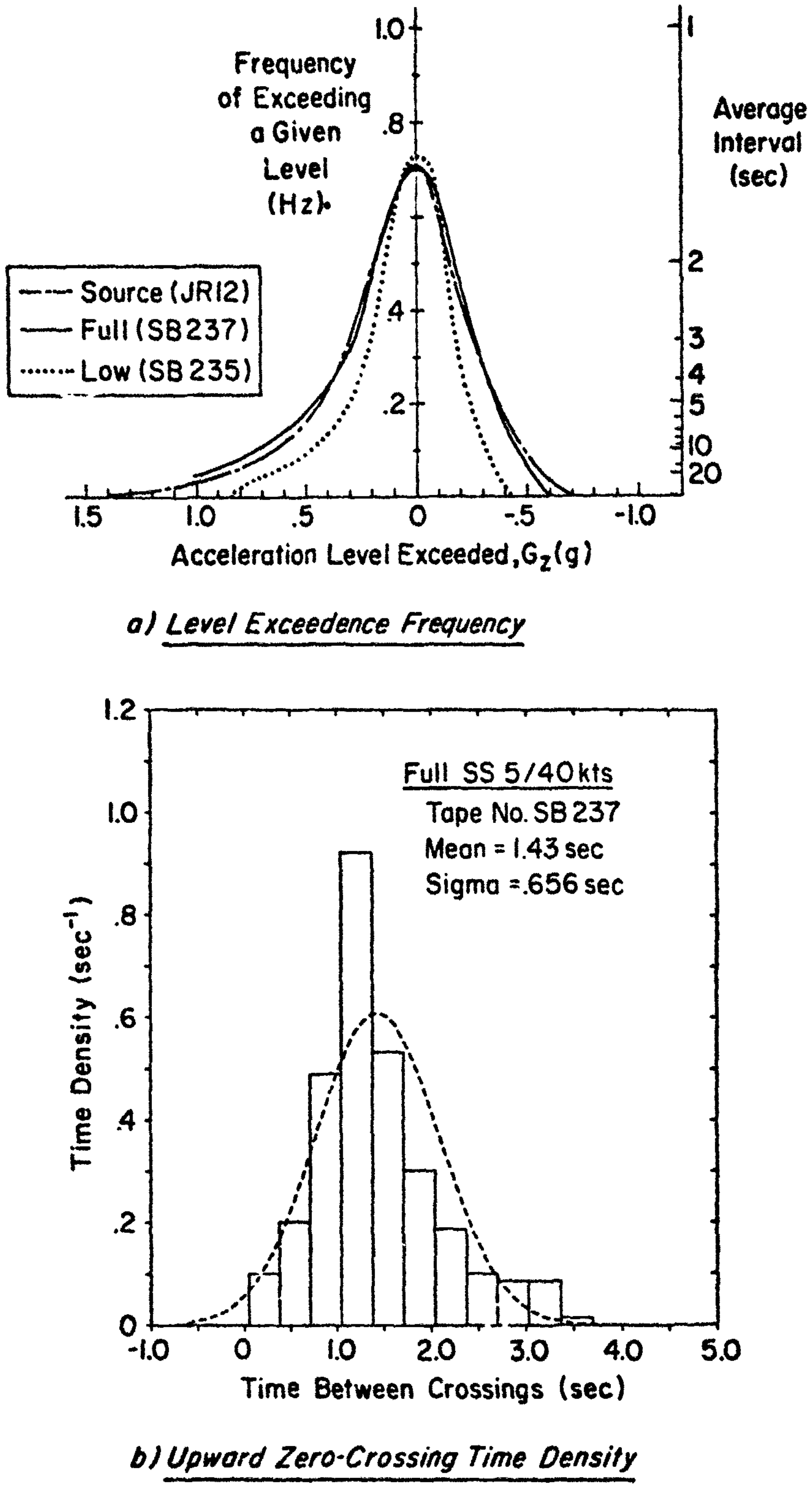


Figure III-13. Amplitude Probability Densities for Source and Typical Measured Starboard Bow Sea State 5/40 kt Conditions



a) Level Exceedence Frequency

b) Upward Zero-Crossing Time Density

Figure III-14. Level Crossing Statistics for Source and Typical Measured Starboard Bow Sea State 5/40 kt Conditions

The source and the measured power spectral densities shown in Fig. III-15 for the SS 5 conditions compare fairly well, but are not quite as precisely matched as those for the two other sea state/speed conditions. However, the small differences are not reflected in the ISO spectra presented in Fig. III-16, over the frequency range of interest, which includes ISO center frequencies between 0.2 and 1.25 Hz, (0.18 to 1.41 Hz edge-to-edge) accounting for 99% of the total rms heave acceleration.

In summary, during Phase II the upgraded ONR/HFR Motion Generator provided motions representative of those calculated for a generic 2000 Ton SES at three tested sea state/ship speed operating conditions, accurately reproducing the heave motions which dominate these conditions with great fidelity over their respective range of interest (roughly 0.16 to 1.6 Hz).

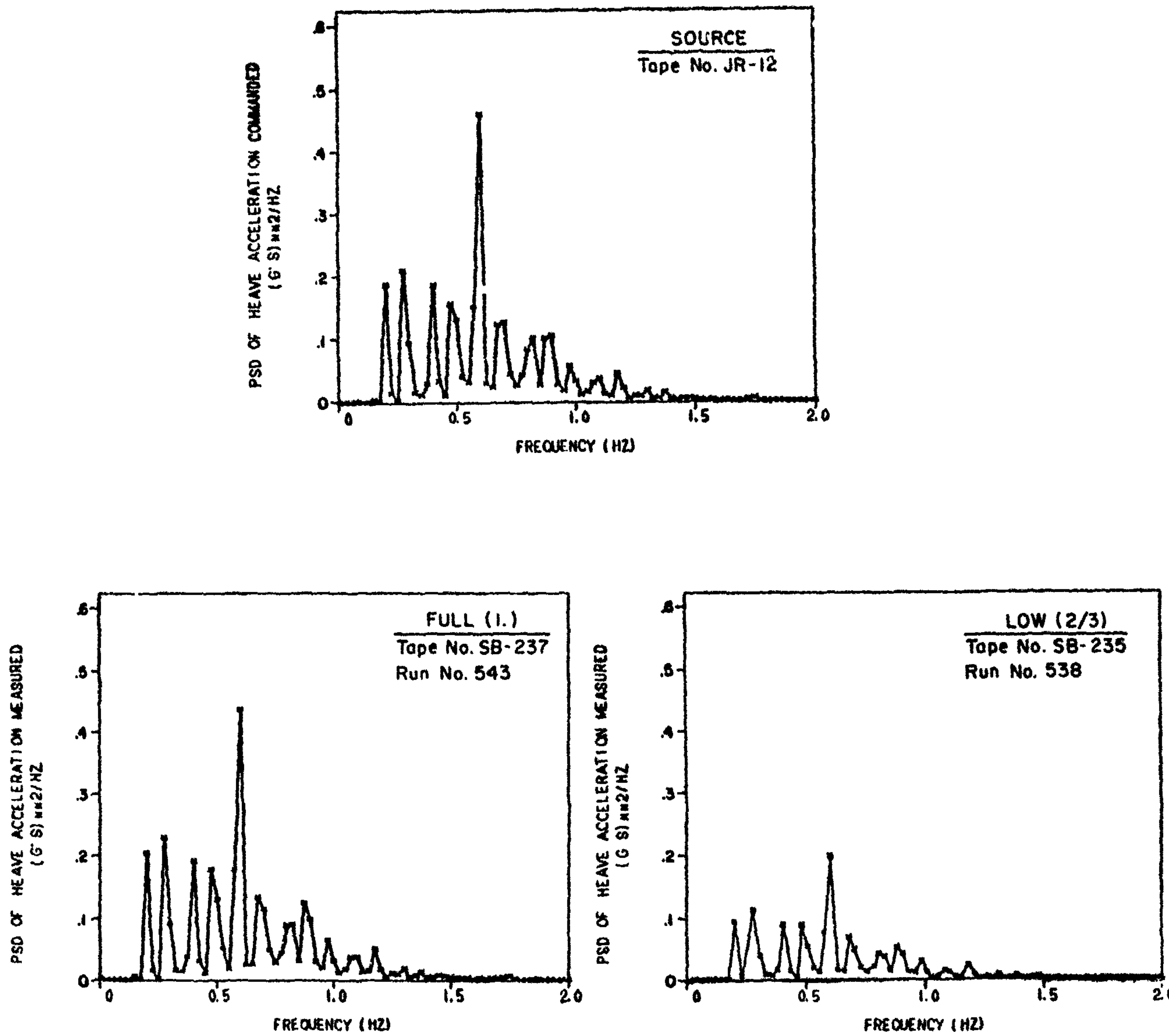


Figure III-15. Power Spectral Densities for Source and Typical Measured Starboard Bow Sea State 5/40 kt Conditions

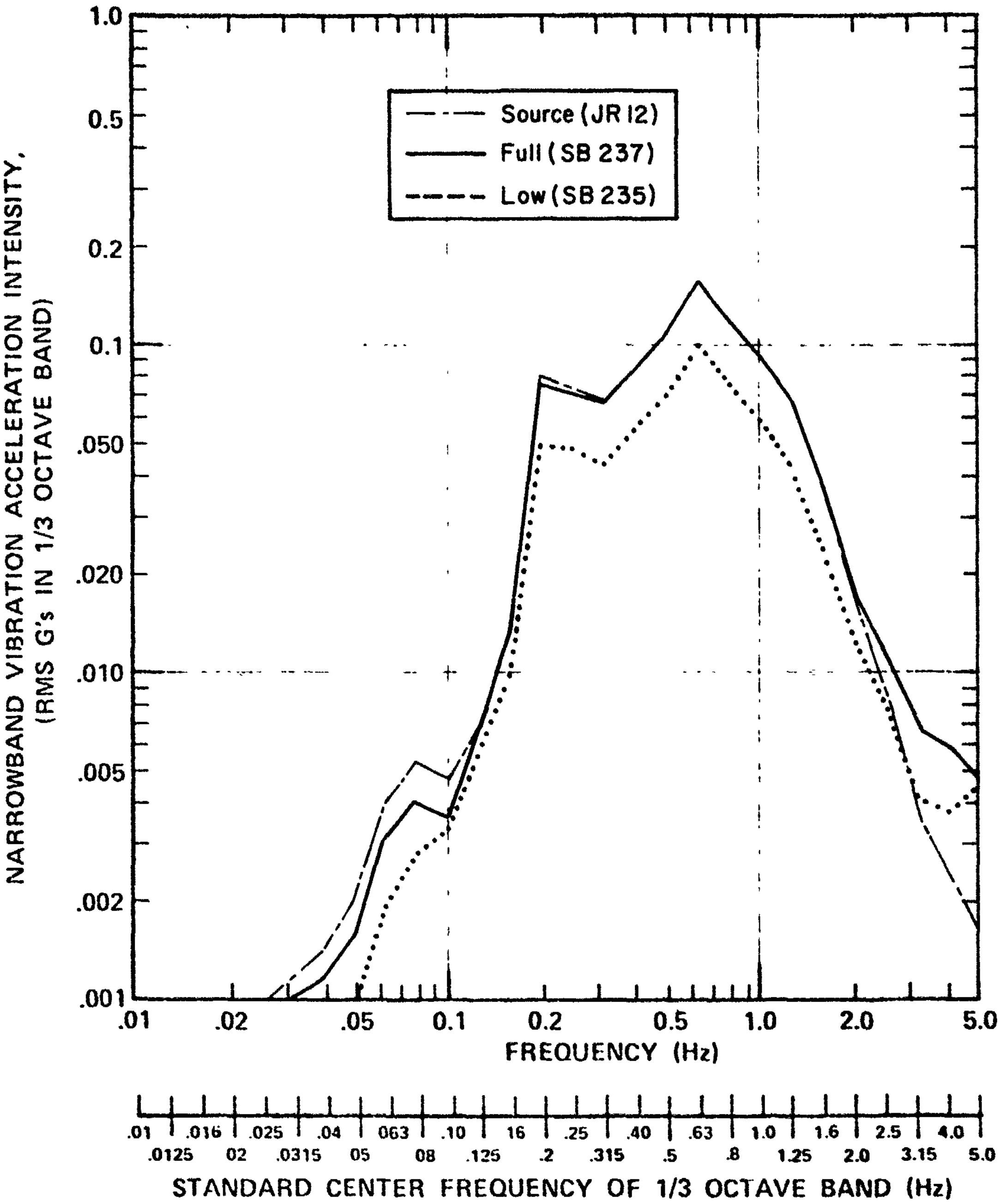


Figure III-16. Comparison of ISO Spectra for Source and Typical Measured Starboard Bow Sea State 5/40 kt Conditions

SECTION IV

TEST SCHEDULES

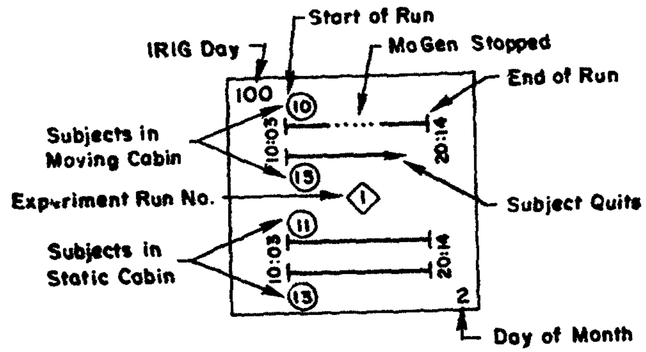
A. RUN CALENDAR

The Phase II simulation was accomplished over three consecutive one month intervals, corresponding closely with the calendar months July, August, and September 1975. The first week of each month was set aside for simulator maintenance and checkout, and preparation for that month's tests. During the second week the group of seven subjects which comprised that month's "team" (subsequently called, in sucession, the "July," "August," and "September" teams) arrived at HFR. In the four days following their arrival, all seven were introduced to and trained on the various tasks and tests which they would perform during the formal experiment, and they were each given a 15-minute "sampler" motion run: five minute segments at each of the three full conditions, head-to-tail: SS 3, SS 4, and SS 5. Formal experiment runs, which included both the motion runs and interleaved static runs, occupied the last three weeks of each month. These are summarized in Fig. IV-1 in a calendar format which indicates the IRIG day* (upper left hand corner), the day of the week, and the corresponding day of the month (lower right hand corner).

Figure IV-1 shows:

- The day and (24 hour clock) time of each run's start and end
- Whether each was a Static or a Motion run (i.e., whether done in the Static Cabin or Moving Cabin, respectively) (Run 33 in the Moving Cabin was a static run); and if motion, what the simulated condition was

*"IRIG-Day" is defined as the approximate calendar day shown on a console-mo[illegible]d digital clock with format (Day, Hour, Minute, Second) and recordable ti[illegible]de pulses defined by the Inter-Range Instrumentation Group (IRIG). Inadvertently, the normal IRIG Day (Calendar Day + 1) was misset between 15 and 16 August such that it dropped Day 227, thereafter reading the calendar day. All experiment data was logged by the IRIG day shown in Fig. IV-1.



July Team	
Code	Day/Night Sleeper
49	N
38	D
52	N
46	N
47	D
44	D
35	D

Experiment Run No.	MoGen Run No.	Condition in Moving Cabin
1	-	—
2	424	(4/8) SS-3
3	439	"
4	440	"
5	446	(1) SS-4
6	451	"
7	453	(2/3) SS-4
8	454	"
9	455	(4/8) SS-3
10	457	"

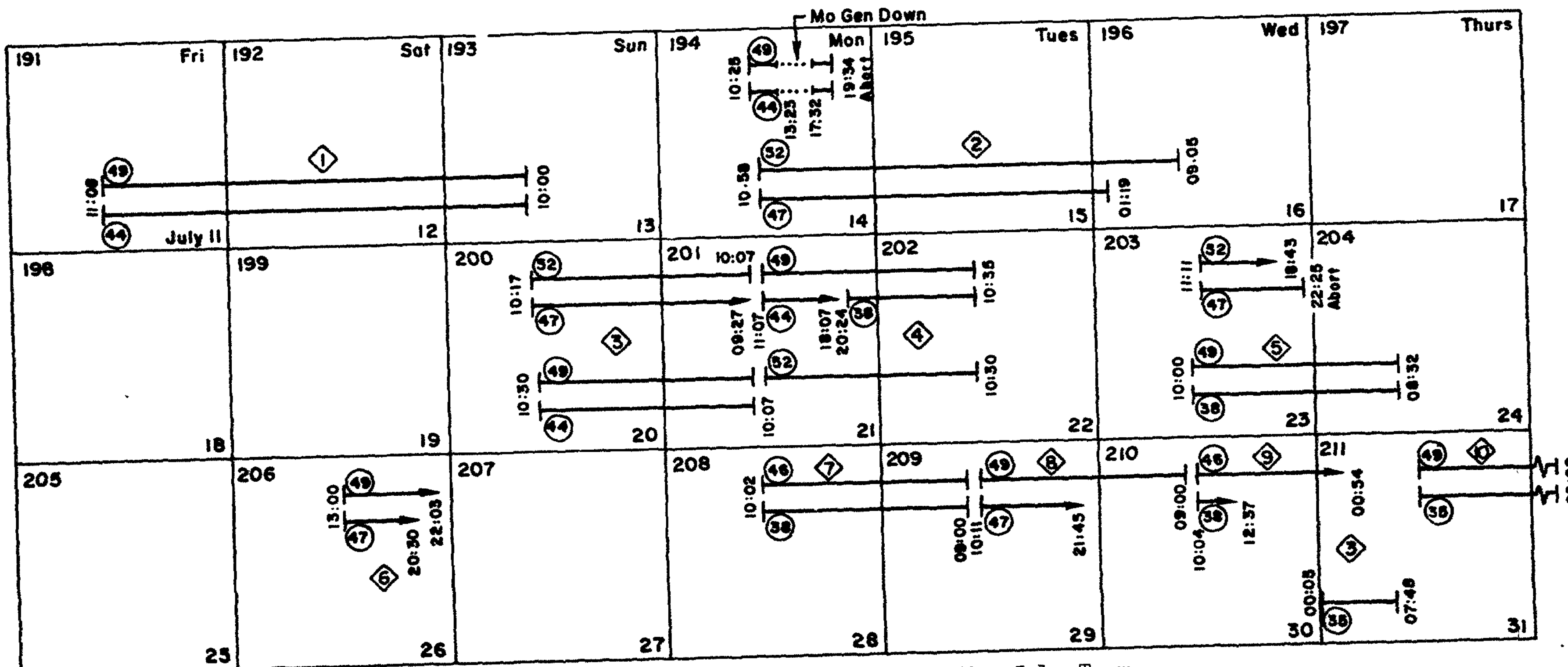
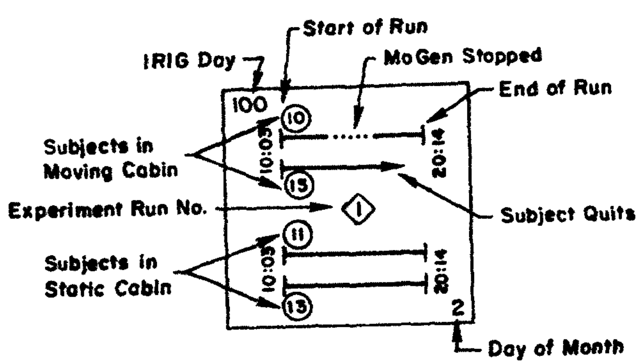


Figure IV-1a. Formal Experiment Run Calendar for the July Team



August Team	
Code	Day/Night Sleeper
43	N
50	D
39	N
48	D
51	D
58	N

Experiment Run No.	MoGen Run No.	Condition in Moving Cabin
11	–	–
12	483	(2/3) SS-3
13	485	"
14	487	(1) SS-3
15	489	"
16	494	(1) SS-5
17	496	"

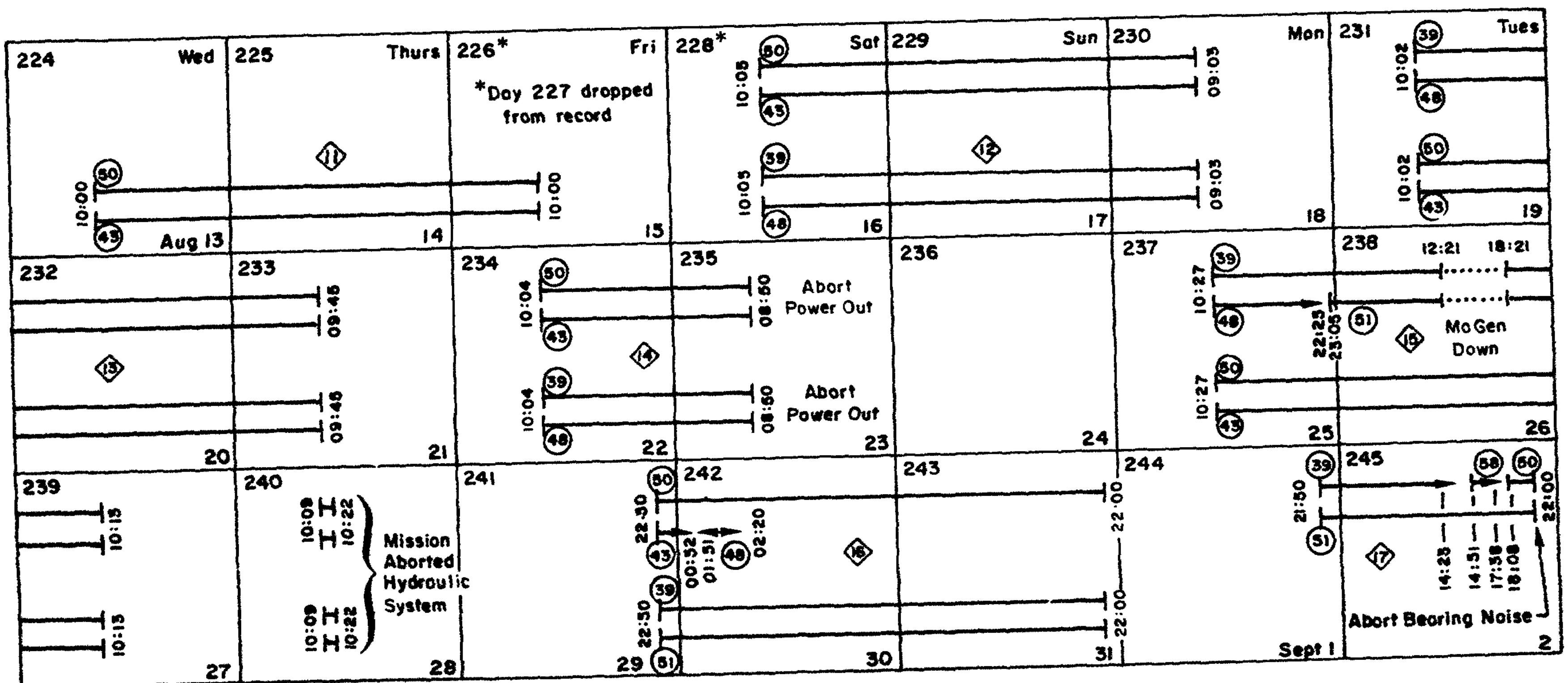
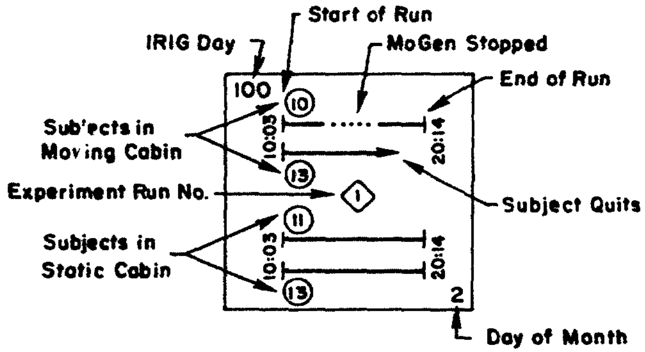


Figure IV-1b. Formal Experiment Run Calendar for the August Team



September Team	
Code	Day/Night Sleeper
60	D
40	N
56	D
61	N
59	D
57	N
43	D
51	N

Experiment Run No.	Mo Gen Run No	Condition in Moving Cabin	Experiment Run No.	Mo Gen Run No.	Condition in Moving Cabin
18	–	–	28	–	–
19	525	(1) SS-3	29	540	(1) SS-4
20	527	"	30	541	"
21	529	(4/5) SS-4	31	543	(1) SS-5
22	530	"	32	545	"
23	532	"	33	–	–
24	533	"	34	547	(1) SS-5
25	535	(2/3) SS-5	35	550	(1) SS-4
26	536	"			
27	538	"			

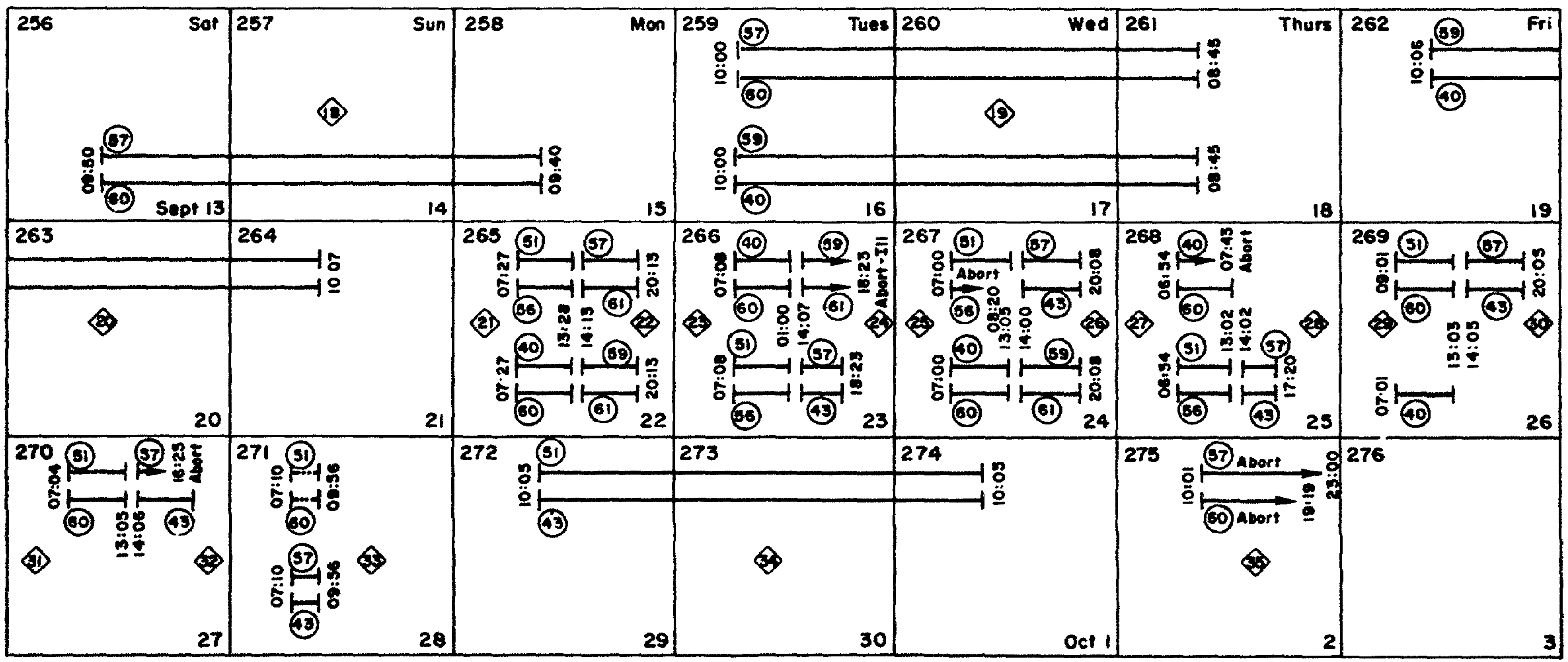


Figure IV-1c. Formal Experiment Run Calendar for the September Team

- Each run's participants (identified only by the last two digits of their NAMRLD code) and the termination time of those crewmen who quit the motion generator (e.g., due to kinetosis) prior to the planned end of the run (indicated by arrow followed by time), as well as the entry time of the latter's replacement if any

- Each month's team members and whether each was on a Day or a Night sleeping schedule (scheduled sleep periods were 1200 to 2000 for Day sleepers and 0001-0800 for Night sleepers)

- A summary of the month's runs cataloged by Experiment Run Number with corresponding MoGen Run Number noted. Experiment Run Number is a sequential designation (by HFR, Inc.) of all formal data runs for this experiment. (MoGen run number is the number assigned in the MoGen Operator's Log which lists all runs including informal ones, e.g., checkout or demonstration runs or early aborts due to MoGen problems

As described in Section III-A, most formal runs were scheduled to go 24 or 48 hours (so-called "long" runs), the only exceptions being the "six hour" mid-September runs which were part of a mini-experiment. In general, the moving cabin was continuously driven by the Motion Generator during all Motion Runs except for occasional brief stops to attach electrodes to subjects just prior to sleep periods (see Vol. 4 for details on sleep analysis via electrophysiological recordings), to remove subjects prematurely terminating the run, or to install their replacements. Occasionally, longer stops were caused by MoGen problems such as discussed in Section III-A. Prolonged (several hour) stops of this type are indicated by dotted subject "time" lines on the run calendar.

B. FORMAL RUN WORK/REST SCHEDULES

The formal run work/rest schedules assigned specific intervals for the performance of various tasks and tests, for the measurement of certain physiological variables, for attending to routine life support functions, and for free time for relaxation and recreation. Subjects were run in pairs with their schedules interlaced, to avoid interference during formal activities due to the limited cabin space. Formal runs and work/rest schedules were arranged so that each subject could maintain his designated

sleep period throughout the test period, both during and between formal runs. (In practice the intended regularity was not strictly observed between runs, especially by the Day sleepers.)

The simulation tasks, tests, and measurements, which were designed to provide data on the interference of SES motions with typical shipboard activities, are listed in Table IV-1 in order of the alphabetical code (which was originally generated for internal use in logging data obtained for the corresponding task) used to identify the task on the work/rest schedules (see Figs. IV-2, -3). The table provides a brief description of each task; indicates at which duty station (per Fig. IV-2) the task was performed; identifies the organization primarily responsible for task development; and shows in which volume the task details and results are presented.

The schedules given below for the long runs and for the six hour runs represent the typical routine and also typify the resulting practice; however, due to a multiplicity of factors, primary among which were: the psychophysiological response of various subjects to the simulated motions (e.g., some were sick and could not perform scheduled activities), occasional MoGen problems (which sometimes resulted in motion stoppages and run delays), and compactness of schedule in the six hour runs, there were some unavoidable deviations for these schedules.

1. Long Runs

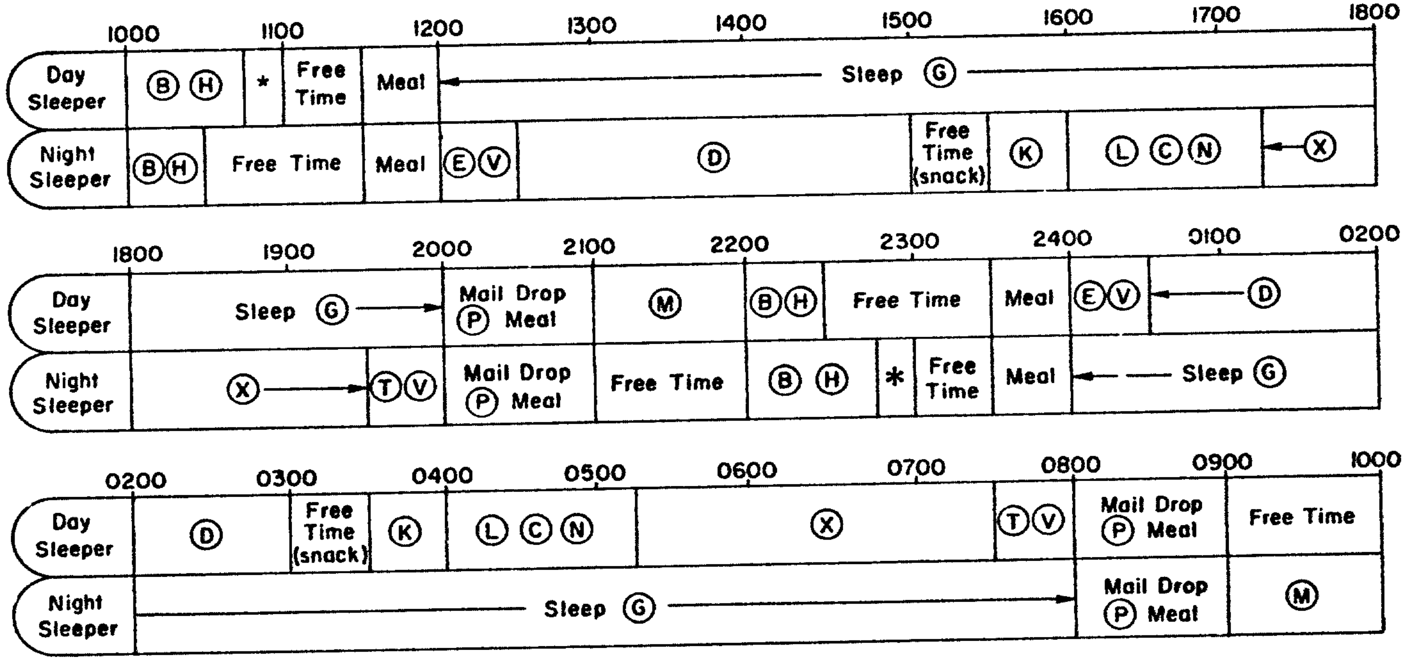
The "long" runs were scheduled to run 24 or 48 hours, though in practice they were sometimes terminated prematurely when both participating subjects found the motion intolerable and no suitable replacements were available. The daily work/rest schedule for these runs is shown in Fig. IV-2; it extends over 24 hours beginning at 1000 (10 AM), the intended start time of each run. For runs lasting longer than 24 hours subjects were recycled through this schedule.

The schedule is written in terms of time-of-day rather than time from run start, thus preserving the regular sleep periods for the participating subject pair during runs beginning at other than the normal start time. As indicated in Fig. IV-2, most of one subject's tasks and tests were done

TABLE IV-1. SUMMARY OF TASKS AND MEASUREMENTS

CODE	NAME	DESCRIPTION	DUTY STATION*	RESPONSIBLE ORGANIZATION	RESULTS IN VOLUME
B	Blood Pressure Measurement	Sphygmomanometer measurement of systolic pressure, sitting	I, III	HFR	4
C	Cryptographic Task	Manual decoding and encoding of written messages	I	HFR	4
D	Missile Detection Task	Air surveillance radar watch (low contact frequency)	III	HFR	4
E	ECM Tracking Task	Antijam Frequency Meter tracking using MK VII 1st-order autopaced Critical Task, dial display, unrestrained knob control	I	STI	3
G	Sleep State Measurement	Electrophysiological monitor of sleep pattern	bunk	HFR/NAMRLD	5
H	Head Motion Measurement†	6-axis miniature accelerometer package, on combination bite-head clamp. Subject assumed various postures sitting and standing while data recorded	III	NAMRLD	5
K	Keyboard Task	Calculating closure rate, intercept time, speed and relative bearing of an approaching object using a minicalculator	I	STI	3
L	Lock Task	One handed opening of a precision four combination lock	I	STI	3
M	Maintenance Task	Disassembling a power supply circuit card using only soldering iron, pliers, and screwdriver	I	STI	3
N	Navigation Plotting Task	Plotting own ship's and radar target positions and courses	II	HFR	4
P	Load Task†	Handling a 13 lb "box" of electronic rack dimensions	I	STI	3
T	Dual Axis Tracking Task	Compensatory tracking of a target using a finger stick and elevation azimuth display	III	STI	3
V	Visual Acuity Measurement	Reading of near point printed material of varying size	III	HFR	4
X	Collision Avoidance Task	Radar watch of nearby ships in heavily trafficked area	III	HFR	4

*Per Fig. II-7 (cabin layout).
†Done only under motion conditions.



*MoGen stopped for 10-15 minutes while electrodes are attached to subject for G .

Notes

- Circled task or measurement codes are defined in Table IV-1.
- Subjects voided in specimen bottles just prior to and right after their sleep periods providing "wake" and "sleep" urine samples for catecholamine analysis used to measure stress.
- Cabin temperature and oral temperature of nonsleeping subjects were measured at, nominally, 4 hour intervals beginning at 1200. Subjective evaluations of sleepiness and of various habitability factors were given at this time. Habitability ratings were also scheduled 30 and 90 minutes into each run regardless of start time
- The load task, P, the head motion measurement, H, and the habitability ratings were given only under motion conditions

Figure IV-2. Daily Work/Rest Schedule for Long Runs

during the other's sleep period. The less formal activities, e.g., eating and recreation, fell primarily within the eight hours during which both crewmen were up and about, allowing for social interchange and cooperative activities between the two.

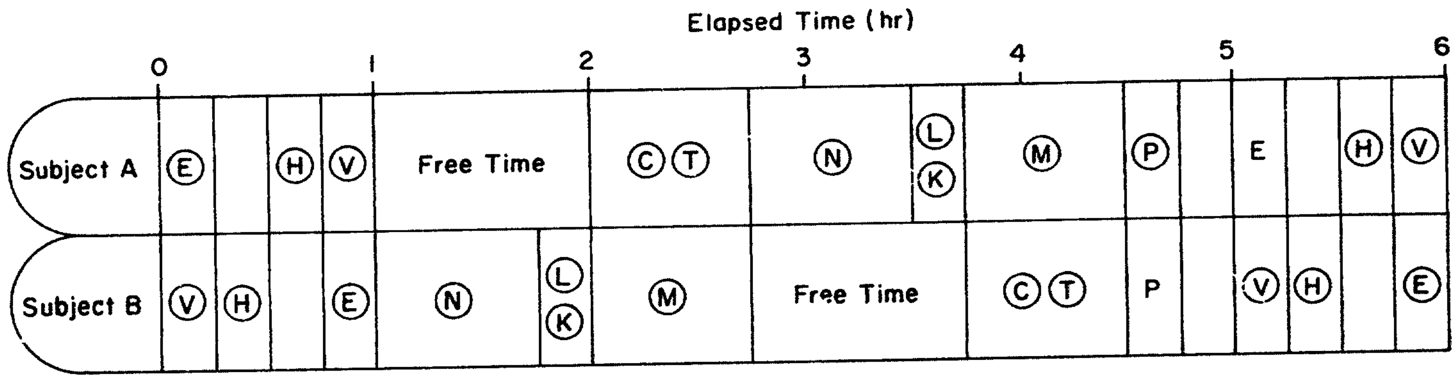
The schedule shown provided for each of the tasks and measurements listed in Table IV-1 to be performed at least once every 24 hours. Blood pressure, Head Motion, and Visual Acuity measurements were made twice per 24 hours, and the Lock Task was performed twice within an hour during the indicated intervals. The Load Task, which is listed twice in the schedule per 24 hours, was added to the task battery during the second month of testing but it was not always done by the August and September teams.

2. Six Hour Runs

As previously described, the six hour runs conducted in September were part of a mini-experiment designed to put as many subjects as possible through an identical set of conditions selected to help expose any differential effects due to intensity and/or waveform of the motion across the SS 3, SS 4, and SS 5 conditions. To accomplish this purpose within the limited time available in September, two runs were made per day: one starting at about 0700, the other at 1400. To accommodate their established sleep schedules, Day sleepers were paired in both the static and the moving cabins for the morning run, while Night sleepers were similarly paired for the afternoon run. Differences between sleep schedules were nominally preserved by a three hours difference in bed time (which was changed from 1200 to 2100 for Day sleepers). The work/rest schedule for these six hour runs is shown in Fig. IV-3.

As careful examination of Fig. IV-3 reveals, the two radar tasks — Missile Detection and Collision Avoidance — were omitted and the Maintenance Task was shortened, because of the time constraints. All other tasks and measurements listed in Table IV-1 were done at least once, with Head Motion measurement, H, ECM Tracking, E, and Visual Acuity measurement, V, done twice.

Because crewman did not sleep during the six hour runs and performed their separate tasks concurrently, there was more potential interference between them. However, this possibility did not seem to cause any real problems.



Notes

- Circled task or measurement codes are defined in TableIV-1.
- Subjects voided in specimen bottles just prior to and immediately after each run, providing pre- and post-motion urine specimens for catecholamine analysis used as measure of stress
- Subjective evaluations of various habitability factors were obtained as many as five times per run (moving cabin only) at, nominally, ½, 1, 2, 4, and 6 hours from the start of the run
- Load task, P, head motion measurement, H, and habitability ratings were done only under motion conditions

Figure IV-3. Work/Rest Schedule for Six-Hour Runs

This section concludes the reporting of those details which underlie the Phase II experiment results, which are described in Vols. 3, 4, and 5 and summarized in Vol. 1. The following concluding remarks are offered with respect to the objectives stated in the introduction:

- Despite the difficulties cited herein, which caused several changes to the original test plan, a relatively large number of volunteer crewmen did undergo comprehensive tests under a wide range of severe motion conditions, thereby greatly increasing the statistical data base at any given condition, as was the primary objective of Phase II.

- To remove the limitations encountered in Phases I and IA, the ONR/HFR Motion Generator was successfully upgraded to reproduce, with a high degree of fidelity, the computed 2000 Ton SES motion for conditions as severe as Sea State 5, traversed at 40 kt — conditions substantially in excess of that achieved in previous programs. The conditions simulated included SS 5/40 kt bow sea and two less severe ones (SS 4/60 kt and SS 3/80 kt), and scale-reduced variants thereof. The three basic (source) conditions were widely different in character, and these differences are documented and statistically analyzed herein. The commanded motions were accurately reflected in the measured MoGen waveforms.

- To meet the secondary objectives stated in the introduction, the measured motions were analyzed in greater detail than in the preceding program phases. These motion statistics, presented herein, should enable other users of this research to gain further insight into the various objective and subjective effects of motion reported in Vols. 3, 4, and 5 of the complete report (Refs. 2-4).

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